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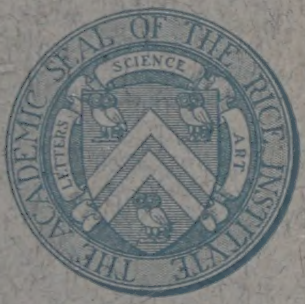

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SCIENCE AND HUMAN WELFARE[1]

I

BIOLOGY AND MEDICINE

MY SUBJECT this afternoon is "Biology and Medicine," but I think a more accurate wording would be "Medicine and Other Phases of Biology," for to my mind Medicine is a branch of Biology. Webster's Dictionary defines medicine as the science and art dealing with the prevention, cure, or alleviation of disease. Biology is the science of life. Disease might well be defined as life out of balance, and is in a strict sense a biological process. Whether it be an attack by microorganisms, or improper functioning of glands, or congenital misformation or maladjustment, or injury by poison or bullets, disease processes are in the last analysis nothing more than cells, tissues, or organs that have suffered injury and so not only fail to perform their normal functions but in most cases interfere with the normal functions of other parts, more often than not of the entire body.

Of the two great divisions of medicine dealing respectively with treatment and with prevention, the former is much the older. It is far easier to observe the effects of treatment on a person suffering from a malady than it is to understand why someone else escaped it. Some knowledge of curative or alleviative medicine was possessed by our cave-dwelling ancestors; in fact, it is instinctive in many lower animals. It gradually grew up as a sort of folklore from a slow process

[1]Public lectures delivered at the Rice Institute on Sunday afternoons in the spring of 1943.

of trial and error, added to the instinctive knowledge acquired from pre-human ancestors.

With the growth of belief in the supernatural, by which man satisfied his developing desire to explain things, medicine became largely theological. Priests and physicians were one. They conceived disease as the work of devils, gods, or spirits which had to be appeased by sacrifices, confused or circumvented by charms or incantations, evicted by emetics, cathartics, or blood-letting, or enticed to escape by means of holes in the skull, nasty medicine, or other devices. It is since the days of our Pilgrim Fathers that we have learned that it is more effective to control typhoid and cholera by boiling water than by boiling witches.

Although belief in the instrumentality of demons and witches in causing disease persisted for a long time, since Hippocrates more enlightened individuals have recognized at least some kinds of disease as natural processes. From that time to the present medicine has been primarily biological instead of theological or metaphysical. Some of the original ideas were, as would be expected, very far astray; for example, the theory that Hippocrates inaugurated and Galen expanded that proper proportions and relations of four humors of the body were responsible for health or disease. According to this theory people were sanguine, phlegmatic, choleric, or melancholic in temperament depending upon which of the four humors predominated. Erroneous as it was, this theory was a long step forward in that it focussed attention on natural instead of supernatural causes, and on caring for the patient instead of appeasing devils.

Hippocrates was also an exponent of the great biological principle that nature is the greatest physician of all. Left alone, an organism attempts to repair damage to its parts, to adjust itself to any unbalance in structure or function

that has been entailed, and to fight off attacks by parasites. The rôle of the physician is to aid the organism in these attempts. In many cases this involves nothing more than augmentation or speeding up of natural biological processes that the organism itself would employ, such as stimulation of immunity, supply of additional antibodies, provision of new tissue or fluid in the form of grafts or blood transfusions, supply of abundant vitamins, regulation of hormones, removal of unhealthy tissue, and protection against invasion by micro-organisms. In some cases it involves methods which are entirely foreign to the natural processes of the animal body, but which aid and abet these processes, such as the use of stimulants, anaesthetics, specific drugs, X-rays, radium, or heat.

The speeding up of natural processes of repair or adaptation is applied biology. It involves a thorough knowledge of the normal biology of the human body—its anatomy and all phases of its physiology. Strangely enough, even knowledge of the gross anatomy of the human body was extremely sketchy and mostly wrong up to the middle of the sixteenth century.

Galen, of the second century A.D., was the father of anatomy for years, but he was a very poor father and his offspring was a very hodgepodge anatomy, arrived at from observations on the inner workings of monkeys, pigs, dogs, and cattle. For over a thousand years man was supposed to have a segmented breastbone like a monkey, a liver divided into as many lobes as a pig's, a uterus with two horns like a dog's, a hipbone flared like that of an ox, and a heart with pores between the right and left ventricles. If in the meantime any errors were discovered in Galen's descriptions the fault was always thought to be either with the patient or with the later observer. When Vesalius, in the sixteenth

century, showed that man's hipbones certainly were *not* flared as Galen described them, it was thought that they had undergone a change in the intervening centuries due to the habit of wearing tight trousers.

The study of anatomy was retarded greatly by religious and civic taboos on dissection of human bodies, but Vesalius spirited skeletons from beneath gallows and was not above occasional clandestine disinterments. He made important contributions to human anatomy, and did much to start other physicians consulting nature instead of Galen. Vesalius even reached the threshold of the discovery of the circulation of the blood, but this great milestone in the history of medicine was planted by Harvey in the seventeenth century. Probably no other single physiological discovery has had such profound consequences. What a superlative age that was, to produce a Harvey, a Shakespeare, and a Galileo!

In the eighteenth century advances were more rapid. It was in that century that another great Englishman, John Hunter, discovered that if arteries are tied off the blood will find and develop new channels. Prior to that discovery aneurisms, which were distressingly common, were treated, if at all, by amputation of limbs. John Hunter also learned some of the tricks of grafting skin and bones.

In the next century, the nineteenth, two other fundamental biological principles—the cellular structure of bodies, and evolution—came to light. Both of these ideas contribute so much to our knowledge of the human body and how it works that a full evaluation of their significance in medicine would be almost impossible.

Even with all these advances in anatomy and physiology, nobody up to the middle of the seventeenth century had any good idea what disease was or whence it came. An important forward step was made in 1687 when two Italian scientists,

Bonomo and Cestoni, showed that scabies was a disease caused by tiny mites burrowing and reproducing in the skin, and was spread by transmission of the mites. This was the first demonstration of a specific cause for a disease, and the first explanation of its spread, and was a clean break from the divine, humoral, or other ancient theories of the spontaneous origin of disease.

A few pioneering minds, a century or two ahead of their times, propounded theories of contagion, and spread of disease by dissemination of poisonous particles or gases, or even invisible living organisms, but there was no experimental evidence, and these precocious ideas fell on barren ground. A true understanding of infectious disease had to wait for the discovery of micro-organisms and some knowledge of their nature.

Leeuwenhoek, a Dutch lens grinder of the seventeenth century, who invented a compound microscope capable of bringing bacteria within the range of visibility, is sometimes called the father of bacteriology, but I think he might more properly be called its midwife. He was one of the greatest explorers of all time. Magellan and Columbus are credited with discovering continents, but Leeuwenhoek opened the door to an entire new world. Wherever he looked—in soil, water, food, excretions, or decaying materials—he discovered a host of micro-organisms that nobody had ever seen before or even suspected of existing. Modern explorers with electron microscopes are having a great time too, but their discoveries of molecules and viruses and of the minute anatomy of bacteria is hardly to be compared with the new world that Leeuwenhoek found under his microscope.

But I do not think that knowledge of the existence of insects makes an entomologist, or knowledge of the existence of stars an astronomer, so I hesitate to consider Leeuwenhoek

the father of bacteriology. That honor, I think, should go to Pasteur who, within the lifetime of my parents, made bacteriology a science. He did it by providing final proof that germs, like all other forms of life, require parents, and come only from pre-existing germs. As long as it was thought that germs developed spontaneously from decomposing materials the bacteriologist was in as hopeless a position scientifically as a mathematician would be if the sum of two and two varied with the weather.

From the standpoint of the control and prevention of disease this was undoubtedly the most momentous discovery ever made by man, for it alone provided a solid foundation for practically all our public health work. On it rests all our theory and practice concerning contagion and infection, quarantine, sterilization, antisepsis, aseptic surgery, purification of water, pasteurization of milk, and almost everything else on which modern practices of public health and hygiene are based. Pasteur is rightly revered for his great contribution in proving the germ theory of disease, but this would have been of little value or significance without the final abolition of the idea of spontaneous generation, which for a long time extended even to maggots and mice.

Pasteur's fundamental discoveries led almost at once to practical applications. Lister in London was quick to apply them to surgery, and by very generous application of carbolic acid to himself, the patient, the bedclothes, the air, and even the floor he brought about a very considerable reduction in the mortality from operations, which had previously been about 45 per cent even in his expert hands.

During the eighteenth century Europe suffered from great epidemics of childbed fever—at one time it got so bad that in Lombardy it was said that for a year not one woman lived after bearing a child. Europe's lying-in hospitals for

destitute mothers were humane in spirit only, in reality they were death traps. Oliver Wendell Holmes proclaimed childbirth fever an infectious disease, carried from patient to patient by physicians and midwives. Many physicians were incensed at the imputation that their hands were not clean, and Holmes's ideas didn't make much headway. It was Semmelweis of Vienna who finally dealt the death blow to childbed fever as an epidemic occurrence, and proved that even an eminent gentleman's hands are not always clean. It is within the memory of many in this audience that aseptic surgery finally supplanted Lister's heroic antiseptic measures, and that surgeons began paying more attention to washing their hands before an operation than after it.

Some twenty years after Pasteur's demonstrations of the germ cause of disease and the final putting to rest of the theory of spontaneous generation, Robert Koch developed technical methods that made possible the easy isolation and study of particular kinds of germs, and then discovery followed discovery with almost incredible rapidity. In the short space of fifteen or twenty years the causes of the majority of infectious diseases of man and animals were isolated and studied. The elusive and rather mysterious agents of disease that we call viruses, however, had to wait much longer for biologists and chemists to pry into their private affairs, and it is only now that very much progress is being made.

An infectious disease is, however, an extremely complicated phenomenon. The interaction of a parasite and its host is not a static thing like the interaction of one chemical with another, capable of simple description, and following a well-defined course. We may be too prone to think, because we know what organism causes a disease, and something about its biology, that we understand the disease it causes. Nothing could be further from the truth. We are dealing with the

interaction of two organisms both of which are capable of an amazing degree of adaptation to changing conditions. Every change or adaptation in one entails further adaptations in the other. A disease may be compared with an organism—it is born, it grows, it adapts itself to environment, and it finally dies. During its life it is influenced by a host of environmental factors which may profoundly alter its course.

An infectious disease depends on the presence of a specific invading organism, but this may be only one of the necessary requisites. In almost every epidemic the number of healthy carriers—people who temporarily acquire a colony of the germs but show no evidence of disease—far exceeds the number of cases. In an epidemic of cerebrospinal meningitis healthy carriers of the organism that we say causes it may outnumber the clinical cases 20 to 1. In most epidemics of such diseases as diphtheria, whooping cough, dysentery, and even cholera, the ratio is from 5 or 10 to 1.

If disease develops in only one-fifth to one-twentieth of the people reached by a particular pathogenic germ, it is evident that there are other factors playing very important rôles in its production. Among these are a proper balance of the glands of internal secretion, good nutrition, especially with respect to vitamins, and the development of specific immunity or resistance. There can be no doubt that these same factors play a large part in determining the course and outcome of a disease after it has gotten a start. A physician, then, if he is to make the most of his effort to help in suppressing disease, must be far more than a dispenser of medicine. He must, indeed, be familiar with more phases of biology than are most biologists. He must understand anatomy, histology, general physiology, endocrinology, embryology, psychology, nutrition, immunology, and even genetics in

order to have a proper understanding of his patient, and he must be a bacteriologist or parasitologist to understand the capabilities and vulnerabilities of the invading organism.

Some relations of heredity and genetics to disease have been known for a long time, but more progress has been made in genetic control of disease in plants and even in domestic animals than in man. Effects of genetic constitution of human beings on the course of disease and development of resistance are still very little understood, and still less is known about effects of genetic constitution of pathogenic organisms and means of altering it. Herein lies an almost untouched field with vast possibilities for the future.

Experimental breeding of mice has resulted in decreasing mortality from a particular disease from 82 to 24 per cent in six generations, and to 8 per cent over a period of years. In six generations of chickens mortality from fowl typhoid decreased from 85 to 10 per cent. Recent studies indicate that alterations in genetic constitution comparable to mutations in insects and plants occur also in bacteria and even in viruses. In a period of a few hours many kinds of bacteria and viruses may reproduce in such numbers that if their rate of mutation is comparable with that thought true for fruitflies, each gene the bacteria possesses should mutate at least once. With even slightly favorable selection, replacement of the parent population by mutants is possible in short periods of time.

Viruses have many characteristics of genes, differing principally in their ability to move from cell to cell. There is evidence that the mutation of viruses is comparable with mutation of genes. The development of relatively non-pathogenic varieties of viruses or bacteria is the real basis for the production of effective vaccines against such diseases as smallpox and yellow fever, and probably for the rise and fall of

epidemics of cholera and diphtheria. It has recently been discovered that the virus of infantile paralysis genetically altered by mouse-adaptation, when mixed with the parent virus, has great power to protect monkeys from paralysis. What causes the protection is not yet known, but the results of this basic discovery may be very far-reaching.

Concomitant with development of knowledge of causes of infectious diseases, immunology was beginning to make its contributions to the cure and prevention of disease. You are all familiar with Jenner's discovery in 1798 of the protective value of cowpox inoculation against smallpox. As the result of that there is probably no one in this audience with a pock-marked face, whereas in Jenner's day certainly one in four of you would have been so marked if indeed you were alive at all. Jenner, however, had no notion of how his method worked; he merely observed that it did, and risked the ridicule of the medical world by saying so, and the life of his own son by testing it.

Many decades later Pasteur, making the most of an accidental observation, laid a foundation for modern immunology by showing that agents of disease can be attenuated by various means to a point where they are no longer capable of producing serious disease, but still possess the power of stimulating immunity comparable with that produced by recovery from a real attack. Just as bacteriology opened the gates to knowledge of the causes and means of transmission of infectious diseases, so the birth of immunology opened the way to knowledge of nature's principal means of combatting them.

The contributions of immunology to the cure and prevention of disease are so numerous that I can mention but a few. As aids in diagnosis I may mention the tuberculin test for tuberculosis in cattle and man; the Schick test for suscepti-

bility to diphtheria; the Dick test for susceptibility to scarlet fever; the scratch test for allergies to pollens, foods, or other substances; the agglutination tests for typhoid, dysentery, cholera, typhus, and many other diseases; the Wasserman, Kahn and other tests for syphilis; the typing tests for the pneumococci of lobar pneumonia; and many others that are less well known but no less useful when needed.

As therapeutic aids I may mention antitoxins for diphtheria, tetanus, scarlet fever, and a number of other diseases, which have made deaths from some of these diseases under ordinary conditions nothing short of criminal negligence; the helpful injections of typed pneumococcus serum in pneumonia; the use of immune or convalescent serum in cerebrospinal meningitis, anthrax, measles, and most recently influenza; and the life-saving properties of anti-venin for snake bites.

As preventive aids I need only call your attention to the wonderful records achieved by the use of vaccines against typhoid, paratyphoid, diphtheria, and more recently yellow fever. This once dreaded disease is now looked upon by the U. S. Public Health Service as of less consequence than the relatively mild and tolerated dengue fever, merely because our government has a bank of a million protective doses of vaccine which it can release if ever a case occurs within our borders. In recent years success has also been attained in production of vaccines against typhus fever and spotted fever, the former of which has hitherto been the scourge of every great war. In the present war man-made implements of destruction are more deadly than ever before, but there is no question but that this added deadliness is more than compensated for by protection from diseases, which, up to the time of the Spanish-American war, always wrought more havoc than the enemy. Such diseases as typhoid, dysentery,

typhus, tetanus, and yellow fever have been shorn of their power by protective vaccinations.

Closely related to the field of immunology is blood typing, which has placed blood transfusion on a safe and sound footing, and made it as routine a procedure as anesthesia or surgical asepsis. In spite of the accomplishments in the field of immunology in recent years, I think we may confidently look forward to ever greater things in the years to come. Within the past twelve months success has been attained for the first time in the artificial production of antibodies in laboratory flasks. This may open the door to future developments which may surpass anything we have yet been able to hope for.

I wish now to turn your attention to another field of biology that has contributed enormously to medicine—the science of endocrinology. No sorcerer or magician of old ever dreamed of accomplishing the miracles that can be performed today by the application of knowledge in this field. Osler, speaking of the effect of thyroid extracts on those horribly misshapen, doltish creatures known as cretins, says, "Not the magic wand of Prospero or the brave kiss of the daughter of Hippocrates ever effected such a change as that which we are now enabled to make in these unfortunate victims, doomed heretofore to live in helpless imbecility—an unmistakeable affliction to their parents and their relatives."

The science of endocrinology was born of primitive beliefs in organ magic. When our remote ancestors began to indulge in the art of thinking and had reached the stage at which they could weave together a number of scattered observations and come out with a general idea, it was a natural deduction that the kind of food you ate was a big factor in determining what sort of person you were. Tigers were thought to be fierce because they ate raw meat; it was overlooked

that a tiger fed on lettuce and carrots would undoubtedly be fiercer still, and that a meat-eater *had* to be fierce to get his meat whereas a vegetarian could afford to be timid and fleet-footed. Such thoughts, travelling along a single track, eventually reached the conclusion that courage could be acquired from eating the hearts of courageous animals or men, intelligence from eating brains, and so on. The psychological effects undoubtedly provided ample circumstantial evidence for the truth of the assumptions.

Modern endocrinology began in 1889 when a famous French scientist, Brown-Sequard, claimed remarkable rejuvenating effects in himself from injection of gland extracts. His results, too, were probably psychological, but his prestige was such that his claims started a development in medicine that has had more profound significance than any since Pasteur's discoveries of the bacterial origin of disease.

The human body is a highly automatic, self-regulating mechanism. Nature's primitive means of regulation of the body of an organism is by chemical substances secreted by its tissues. Superimposed on this, later in evolution, is an involuntary nervous system, useful in making rapid and temporary adjustments that become necessary for a body with ever-increasing activities and more and more complicated relations to its environment. Still later in evolution Nature added a voluntary nervous system but very wisely refrained from giving it control over the internal regulation of the body. As Dr. Cannon remarks, we should be greatly bothered if in addition to attending to the business of other people we had to attend to our own. The internal affairs of the body are too important to be subject to a well-meaning but neglectful and incompetent intelligence, which would as likely as not be concerning itself with the flight of a golf ball when it ought to be attending to the rate of the heart beat.

The chemical method is still the fundamental means of regulation of the body. Chemicals produced by tissues, which we call hormones, control such functions as growth, development, metabolism, and reproduction, and adapt the body gradually to climatic fluctuations, variations in activity, nutritional changes, pregnancy, lactation, etc. The human body is one of the most thoroughly integrated and communistic organizations imaginable, every part sharing, according to need, with every other part, and each part influencing every other part. It is a prevalent view today that every tissue and organ in the body produces hormones or hormone-like substances that help in the integration of the entire organism. As bodies became more complex during the course of evolution, however, and the regulation more difficult, a number of special glands for production of particularly potent hormones were developed. These are what constitute the endocrine system. Some of the glands are completely separate organs having no other functions, such as the thyroid, pituitary, and adrenals. Others have developed as special tissues in already existing organs, as in the pancreas, liver, and sex glands.

The potency of these glands is almost incredible. They very largely determine what we are and how we behave. They dominate our physical stature, our mental development, our emotional status, our reproductive activity, the rate at which we live, and our ability to make use of our food. They are the architects of our bodies and the moulders of our character. A puppy deprived of its anterior pituitary gland may be converted from an aggressive, pugnacious creature to a whimpering coward, and may be returned to its former state by pituitary injections. Injections of prolactin into rats with no trace of maternal instincts will fill them so full of mother-love that they will even mother baby

squabs instead of eating them. One is led to interesting speculation as to whether injections of prolactin might not be a good alternative to execution for despotic dictators.

The hormones produced by the endocrine glands, some stimulating and some inhibitory, not only affect the body as a whole in many complex ways, but they interact with each other in such an intricate manner that we are still very far from ideal utilization of them, and we may look forward to a great extension in the future. Yet even now, only fifty years from the birth of the science, the use of hormones has revolutionized a large part of medical practice and has given new insight into many physiological processes, such as metabolic rate, sugar metabolis n, blood pressure, menstrual disorders, psychotic maladjustments, adiposity, sexual aberrations, and reproductive difficulties.

Now let us turn to another contribution of biology to medicine—knowledge of nutrition. For lack of time I will pass briefly over many interesting discoveries connected with metabolism of proteins, fats, and sugars, utilization of minerals, etc., though in passing I must pause long enough to mention a relatively new tool in physiological research—the use of ions tagged by means of atoms of unusual weight or made radioactive in cyclotrons. By this means it has been found that molecules in the body, even those supposed to be relatively stable in bones, teeth, or fat, are forever being shifted about and replaced by new ones. The body is even less stable than it was thought to be.

The most significant discoveries in nutrition, ranking close to the discovery of hormones in their importance to human welfare, were those of the vitamins. Since the days of leopard skin dinner jackets and struggles with cave bears instead of dictators, man's ways of life have undergone many changes and so have his foods. With the development of

agriculture and civilization his food became less varied and more highly manipulated. He began to live more extensively on grain, to store food for periods of famine, and to cook it. Later he began throwing away the vitamin-bearing parts of his cereals, developed a taste for refined sugar, protected himself from sunlight, and often lived for months without fresh fruits or vegetables. Beriberi, scurvy, rickets, pellagra, and night blindness attacked whole populations.

Except for the cure of scurvy by eating lemon juice or hemlock leaves some two hundred years ago, nothing definite was known about these nutritional deficiency diseases until Eijkmann began experimenting with diseased fowls in Java forty-five years ago. Gradually during the last thirty years a whole alphabet of vitamins has been discovered, but it is only within the last decade that they have been obtained in chemically pure form, and synthesized. Few people even today realize the importance of this. Although this country is probably the best fed in the world, I do not believe it is an exaggeration to say that 50 and possibly 75 per cent of the American people do not have optimum amounts of all the vitamins they should have. They do not have scurvy or beriberi or rickets, but they have a host of minor illnesses or troubles that they need not have. Some British authorities have gone so far as to say that 99 per cent of so-called common illnesses are directly or indirectly due to vitamin deficiencies. Allowing 100 per cent expansion for enthusiasm, the figure is still impressive.

The common effects of vitamin deficiencies are such things as night blindness, susceptibility to colds, unhealthy teeth, poor appetite, gloominess, nervousness, and a tendency to fly into tantrums. An abundance of vitamins leads not only to a state of super-health in people who have always considered themselves reasonably healthy, but it is of great help

in recovery from acute or chronic diseases, repair of wounds, and resistance to infection. Even yet, many medical men tend to look upon synthetic vitamins as medicine rather than supplementary food, but gradually this is changing, and it is encouraging to see more and more foods fortified by added synthetic vitamins. Because of this and the more even distribution of vitamin-bearing foods by rationing, the general level of nutrition in England, in spite of several years of war, is better than it has ever been before. It is becoming more and more so in this country too.

The definition of Medicine includes the prevention of disease as well as its cure and alleviation. Some attempts at preventive medicine were made when disease was supposed to be caused by demons, for it was a natural inference that if the demons could be ejected they might also be prevented from entering. With the development of the humoral theories, preventive medicine was almost completely forgotten, since no one had even guessed as to how the humors could be kept in order before they got out of balance. Prevention of disease is a phase of ecology, and involves knowledge of normal bodies and their relation to their environment, including climate, atmosphere, and geological formations, as well as relations to such fellow creatures as rats, mosquitoes, lice, hookworms, amebae, and bacteria, to say nothing of viruses.

It is only in very recent times that anything whatever has been known about this phase of medicine. Only in a few instances have the processes of trial and error that led to curative and alleviative procedures led to practices that prevent disease. One of the first great triumphs in curative medicine was the discovery, in 1640, of the value of extracts of cinchona bark as a cure for malaria, but it was not until the end of the nineteenth century that a basis for the prevention of malaria was discovered.

A few practices of primitive people suggest attempts, probably unwitting, to prevent disease. In India, for instance, I found a primitive tribe, the Santals, who never drink water directly from a stream or pond, but from a little hole in the sand a foot or so away, thus practicing sand filtration, one of the prime tools of modern sanitary engineering. The unfitness of natural water for drinking was recognized long ago. Cyrus of Persia carried boiled water for his troops twenty-five hundred years ago. The low repute of water as a beverage even in the unenlightened middle ages is evidenced by a thirteenth-century writer who, describing the extreme poverty of Franciscan monks who settled in London in 1224, exclaimed, "I have seen the brothers drink ale so sour that some would have preferred to drink water." The head-hunting, carrion-eating Nagas of the Assam hills drink only a rice beer, carrying starters with them when they go on trips.

Preventive medicine as practiced at present has three principal legs to rest on—(1) the upkeep of natural resistance by general hygienic measures, including a proper hormone balance and optimum nutrition; (2) the artificial stimulation of specific immunity or resistance; and (3) protection against access of disease germs via water, food, air, or insect transmission.

The general principles involved in the first of these have been known for a long time, but the details have only recently been filled in by the discoveries with respect to hormones, minerals, and vitamins that I have already mentioned. I have already called your attention to the fact that in an epidemic only a small percentage of the individuals that are actually exposed develop a disease. The determining factors are the dosage of germs that gain access to an individual, and the natural resistance he has. The higher the

natural resistance, the greater the dosage he can withstand.

The second leg on which preventive medicine rests, artificial stimulation of immunity, I have already discussed. On it we depend very largely for our protection against smallpox, diphtheria, tetanus, rabies, yellow fever, spotted fever, typhoid fever, and many other diseases.

The third leg on which preventive medicine rests—protection against dissemination of germs—I have so far said little about, but here enormous strides have been made within a short space of time.

Famous in sanitary history is the case of the Broad Street pump in London in 1854, around which centered an explosive outbreak of cholera. After everything from the chemical nature of the soil to dust bins in cellars had been investigated, the relationship between drinking water from the well and attacks of cholera became clear. Nature had provided a grim lesson out of which grew modern sanitary engineering. In the intervening ninety years modern water purification and sanitary sewage disposal have developed. Whereas in 1900 the American death rate from typhoid was 36 per 100,000, today it is about 1 per 100,000, and in 1942 more than half of our large cities had not a single typhoid death.

Milk and food sanitation are even more recent developments. Even twenty-five years ago a child ran the risk of acquiring disease every time he drank a glass of milk; today the greater part of the milk supply in almost every city is pasteurized, and many cities can boast of having no raw milk.

Just fifty years ago two American workers, Smith and Kilbourne, laid the foundation stone for medical entomology when they demonstrated the transmission of a disease—Texas fever of cattle—by means of a tick. Five years after that the mosquito transmission of malaria was proved and then, at the turn of the century, came the brilliant work of

an American Army Commission in Havana, proving the transmission of yellow fever by mosquitoes.

Today medical entomology plays a large part in our lives. By control of insects, ticks, or mites we are able to control, in some cases almost to exterminate, many important diseases, including some of the *most* important. I need only mention the prevention of malaria, yellow fever, and dengue by mosquito control, of epidemic typhus and relapsing fever by delousing methods, of plague and endemic typhus by control of rats and fleas, and of dysentery by fly eradication.

Already we have become so accustomed to the benefits from all these protective devices that we take them for granted. Only when circumstances interfere with their practice, as is often the case in war, do we realize how much we depend on them. It was dysentery, not the Turks, that defeated the British at Gallipoli, and it was dysentery and malaria, not the Japs, that defeated our own troops at Bataan.

As we go on into the future, preventive medicine will play a larger and larger part in our lives. Instead of being a secondary and relatively unimportant part in the curriculum of our medical schools, I predict that we shall have many schools devoted primarily if not exclusively to this fast-growing branch of medical science, which is still so young that it is seldom allowed to stand on its own feet. The subjects taught will be very largely biological ones, such as medical entomology, helminthology, protozoology, bacteriology, immunology, the newly-developed field of aerobiology, and methods of sterilization and disinfection which are also a branch of biology, since they deal with the destruction of life.

In addition to the categories of discoveries in biology that I have already mentioned, there are other fields of biological research which are making valuable contributions to both preventive and therapeutic medicine. I have time only to

mention in passing a few of the discoveries made in the year 1942.

During the past year great advances have been made in the long-neglected field of aerobiology, dealing with the distribution of pollens, fungus spores, micro-organisms, etc., through the air; new knowledge of the spread of contagion through the air has been obtained, and new methods of control worked out, using vapors and ultra-violet rays. Also within the year there have been a number of new biological methods of controlling pathogenic organisms, including discovery of an enzyme-like substance in young rats, by which tuberculosis bacilli may be shorn of the waxy coats that protect them from drugs and phagocytes, and discovery of germ-killing substances extracted from molds and from various types of soil bacteria. In the field of nutrition, evidence for the need of particular amino-acids for special functions in the body have been demonstrated, and may pave the way for better control of these functions in the future. New methods have been developed for the study of the ultimate connections between nerves and muscles, which may lead to better control of paralysis and muscular diseases. Announcement has also been made of the development of germ syrups, at negligible cost, which change the bacterial life of the human intestine so that, like deer and cattle, we can not only digest the cellulose of grass, leaves, and wood, but can also synthesize our own supply of B vitamins within our own bodies. In research on cancer, which is one biological problem that is still unsolved, a number of significant advances have been made. A few more pieces have been fitted into the mosaic, bringing the final picture a little nearer to completion. In this field as in that of allergies, there is still much to be done, but there is every reason to believe that it *will* be done before very long.

In all these biological accomplishments, we have had to depend to a very large extent on experiments on animals. Few of the great discoveries in physiology, immunology, endocrinology, vitaminology, treatment of infectious disease, anesthesia, surgical procedures, or cancer research could have been made without the help of guinea pigs, dogs, rats, monkeys, or other experimental laboratory animals. Just as brave young men are sacrificed on the field of battle to save us from slavery and degradation, so helpless animals are sacrificed to save us from the bondage of disease. Although we deliberately expose our brothers and sons to destruction for the greater good of our country, we do it with the deepest regret for the suffering they may have to endure, and we make every effort to minimize that suffering. So it is with the biologist and his experimental animals. Contrary to the imaginings of those well-meaning but misguided persons who call themselves anti-vivisectionists, biologists do not enjoy seeing animals suffer; they in fact suffer with them, and relieve them of pain or unnecessary suffering whenever possible. Some biologists may be sadists, but I have yet to meet one.

None but the biologists themselves, and the medical men who profit from their results, can fully appreciate how much, how *very* much, the comfort and safety of the human race depends on the experiments for which their experimental animals have suffered and died. It is difficult not to suspect the reflection of a suppressed sadism in the accuser when one hears experimental biologists referred to as heartless, cruel, or hateful. It should not be forgotten that God sacrificed his only begotten Son that man might live; it is difficult to believe that He would disapprove the sacrificing of laboratory animals that man might have a greater share of health, happiness, and security.

Man's ingenuity has freed him from many phases of the struggle for existence to which other creatures are subject. He has gained an insuperable advantage over the wild beasts, and his inventive genius defies the attacks of climate and the elements. In his struggle against disease he has, as we have seen, made wonderful progress, although he still has far to go. There is some reason to hope that after the present global war has burned itself out we may be able to free ourselves from the one phase of the struggle for existence that man's ingenuity has steadily made more terrible, the struggle of man against man. With all the phases of the struggle for existence well in hand we may then turn to a struggle for improvement of our kind by the application of two other branches of biological science, genetics and eugenics. Within our own generation preventive medicine has grown out of therapeutic medicine; perhaps our children may live to see a still newer branch of "improvement medicine," in which endocrinology, nutritional studies, problems of aging and rejuvenescence, and eugenics will lead to greater health, more happiness, longer life, and better evolutionary prospects than have hitherto been our lot.

Asa C. Chandler.

II

SCIENCE AND PUBLIC HEALTH

PUBLIC HEALTH is a modern term which serves to designate that phase of medical science which concerns itself primarily with the group rather than the individual member of society. According to the present conception, a health problem becomes a public responsibility when it can be controlled only by systematized social action. The most common health problems falling within the scope of the public health program are the communicable diseases, the preventable diseases whether communicable or not, and those health or life hazards which are sufficiently widespread to affect a significant portion of the population. Public health practices had their beginning at the very dawn of civilization. They arose out of the health needs of the people and have developed along with numerous other folk activities incidental to life and living. At no time in the history of its development has the quality of the public health program progressed beyond the intellectual capabilities of the individuals for whom it was intended. The history of the development of the public health movement, therefore, may serve as a sounding board to reflect the life, customs, and scientific attainments of society at any particular period in the history of civilization.

Students of folklore are universally agreed that there is a common point of identity in the myths, superstitions, and religious ceremonies of all primitive peoples. Under different aspects of time and space primitive practices have been

strangely alike, differing only in unimportant details. The common point of convergence in folk-medicine was the belief that disease was a manifestation of the wrath of God, or of some human enemy with supernatural powers. The cure of disease, or its prevention, was therefore closely associated with moral reform, and thus fell within the prescribed duties of the priests. The untutored folk-mind was prone to regard the natural as the supernatural; it confused life with motion and assigned causal relationships to accidental occurrences. In the treatment of illness the primitive physician assumed a directive control over disease somewhat similar to that of the priest in relation to religion. By means of mysterious incantations, and the assumption of various terrifying aspects, the demons of disease were frightened away. To prevent a recurrence of the disease the patient was given a charm to be worn or carried on his person. Throughout this ordeal the patient was no doubt entertained and amused while nature proceeded to cure the disease or kill the victim.

The ancient Hebrews were probably the founders of organized public health. As recorded both in the Talmud and the Bible, the Jewish priests served as hygienic police in relation to contagious diseases, and thus may be considered the first public health officers. Detailed codes for hygienic living are set forth in the Bible. These mandates give directions to the priests as to the method of diagnosing leprosy and other bodily ailments. They prescribe a code to be followed in relation to the proper food to be eaten, the handling of unclean objects, and other matters of personal and community hygiene. In addition they give specific directions for the prevention of contagious diseases, segregation, disinfection, and the proper disposal of bodily wastes and the clothing of diseased persons. It is not to be assumed, however, that the early Hebrews were familiar with the causative agents of

disease or with scientific methods of treatment. As in the case of all healers before them, they relied on superstitious rituals and sacrificial offerings to secure the desired results.

Without the development of the scientific method there would have been little progress in the field of public health. Since science rests on the painstaking recognition of uniformities in nature, the methods of science began when man first learned to record the passage of time. He was thus enabled to plan ahead for the various seasonal activities necessary to life and thereby organize and systematize his mode of living. The development of science, therefore, became an integral part of the common life of mankind and its history is coextensive with that of civilized living. Science is organized workmanship and its ultimate goal is truth. The methods of science separate belief or assumption from fact. They demand accuracy and objectivity in experimentation and observation, and permit interpretation and conclusion only if substantiated by fact. The development of science has never been continuous, nor even progressive, and those who have sought truth through the methods of science have experienced tremendous difficulties. In early civilization the same individual served as physician, scientist, and priest. Because the personal fortunes of the priests rose or fell according to their alleged ability to control the forces of nature, it was advantageous for them to stage dramatic performances for their clientele. Consequently magic came to be inseparably interwoven with science. To the untutored mind pseudoscience was undoubtedly more spectacular than the genuine article and therefore more acceptable. Since the moral leaders were able to exert considerable control over public opinion, they often retarded the advance of scientific ideas and frequently developed into fanatical overlords who oppressed mankind and kept them permanently ignorant and super-

stitious. "Ideas of the greatest scientific moment have been throttled at birth or veered into blind alleys through some current prepossession or deprived of their chance of fruition through human indifference, narrow mindedness, or other accidental circumstances."[1]

The history of the advancement of medicine, and therefore public health, is the . . . "history of the discovery of a number of important fundamental principles leading to new views of disease, to the invention of new instruments, procedures, and devices, and to the formulation of public hygienic laws, all converging to the great ideal of preventive or social medicine."[2] Following the Dark Ages many factors worked to hasten the advancement of the science of public health, the most significant of which occurred during the intellectual awakening of the Renaissance. Advances in the sciences of biology, mathematics, chemistry, and physics made possible new discoveries in the theory of disease. Many other happenings indirectly stimulated the rapid development of public health. Chief among these factors were the invention of the microscope and other scientific instruments, the inauguration of the teaching of medicine and science in the medieval universities, the organization by the Church of hospitals and sick nursing, and the edicts of the Church which resulted in taking medical practice out of the hands of the monks.

Considerable stimulus was given to the advancement of public health by the destructive epidemics which ravaged Europe during the Middle Ages. These diseases were variously ascribed to comets and other astral influences, evil spirits, and the poisoning of wells by enemies of the people.

[1]F. H. Garrison, *An Introduction to the History of Medicine* (Philadelphia: W. B. Saunders Co., 1914), p. 36.

[2]*Ibid.*

The real causes, however, may be attributed to the crowded and unsanitary condition of the walled medieval towns, the poverty, misrule, and gross immorality of the people, the vagabond soldiers, students and other itinerants, and the general ignorance, superstition, uncleanliness, and promiscuous cohabitation of the masses. Among these many epidemics were leprosy, scurvy, influenza, Black Death, and syphilis. The Black Death, now thought to have been bubonic plague, destroyed more than sixty million persons in the fourteenth century alone, and syphilis was so widespread that it reached every corner of the earth and affected all classes of people. Although the destruction of life was appalling and the deleterious effects on morality and decency beyond comprehension, some good actually resulted from these terrible plagues. In an effort to control the ravages of these diseases, the Venetian Republic appointed three guardians of public health and made the first quarantine of infected areas, while in other cities there were plague ordinances, personal instructions as to prevention or treatment of disease, pest houses, and other hygienic improvements. These enactments represent a momentous step forward, inasmuch as the forces of superstition and ignorance which had ruled the world since prehistoric times were finally displaced by systematized methods of scientific disease control.

While present-day public health practices are based primarily on the science of medicine, there is scarcely an area of scientific endeavor which does not make some contribution to organized community hygiene. For indispensable guidance and assistance public health turns to the field of nursing for expert service in the visitation and care of the sick and in other technical services in relation to health and disease; to engineering for contributions in connection with sanitary water supplies, sewage disposal, drainage, indus-

trial hygiene, heating, lighting, and ventilation; to architecture for improved and beautified homes and communities; to chemistry for researches in foods, vitamins, and the application of chemistry to a great array of human activities; to physics for the foundations of applied mechanics; to biology for researches in the area of disease-bearing insects and in heredity and behavior; to psychology for contributions toward a better understanding of the activities of the individual; to sociology for facts leading to a better understanding of group behavior; to ethics for contributions in the field of morals and standards of conduct; to veterinary science for activities in relation to the control of those diseases in animals which may affect man; to economics for studies in the sequence of phenomena in the business cycle, taxation, credit, and consumer education; to political science for contributions toward a better understanding of the functions of government in relation to public health; to mathematics for methods of recording vital statistics and formulae useful in testing the soundness of hypotheses derived from numerical data; to safety engineering and construction for the removal of hazards which are destructive to life and limb; to education for the creation of a literate and enlightened population, and for instructional programs in health and physical education; and to legal science for the contribution of laws favoring hygienic living and the enforcement of these codes in the best interest of public health and welfare.

Perhaps the most effective organization to bridge the gap between scientific knowledge and its practical application in the field of public health is the United States Public Health Service. While several other departments of the federal government deal to a lesser degree with public health matters, the United States Public Health Service makes the health and general welfare of the nation its principal busi-

ness. Founded in 1789, the Public Health Service has recently been made a division of the Federal Security Administration. A study of the activities of this organization will serve to indicate the scope of the field of public health. These activities include investigations of the diseases of man; investigations of matters pertaining to the public health, including child hygiene, industrial hygiene, general sanitation, school hygiene, heating, lighting, ventilation, and milk in relation to health; investigations in the field of mental hygiene, including habit-forming drugs and drug addiction; investigations of water supplies and sewage, including pollution of streams by human and industrial wastes; demonstrations of sanitary methods and appliances in urban and rural communities; control of venereal diseases; prevention of the introduction of contagious diseases from abroad; medical examination of aliens under the immigration laws; prevention of the spread of communicable diseases in interstate commerce; regulation of the propagation and sale in international and interstate commerce of viruses, serums, toxins, and analogous products; co-operation with state and local authorities in public health matters; co-ordination of researches; collection of sanitary reports and statistics; dissemination of public health information by means of publications, conferences, lectures, and demonstrations; co-operation with other departments and services of the government in matters of public health and general welfare, including the Social Security Board, and the Departments of Labor, Interior, Commerce, State, and Agriculture. The United States Public Health Service also serves as a model for the organization and administration of state and local public health departments.

While morbidity and mortality statistics cannot be relied on to reflect all aspects of health, it is gratifying to note that

the years of painstaking devotion to the methods of science continue to produce lowered disease and death rates. No case of cholera has originated in the United States since 1911, and the last case of yellow fever occurred in 1924. During the year 1940 there was an appreciable decrease in the number of cases of most of the infectious diseases and the death rates from these diseases were the lowest in the preceding five-year period. The death rate from pneumonia was unusually low, due in all probability to the more extensive use of improved diagnostic technics and to newer methods of treatment. Mortality from each of the four principal childhood diseases: measles, whooping cough, scarlet fever, and diphtheria, has decreased markedly. Indeed, the death rate from diphtheria has declined nearly 50 per cent during the five-year period preceding 1939. Higher death rates were reported in 1939 in influenza, cancer, diabetes, cerebral hemorrhage, and heart disease. It is to be noted that cancer, diabetes, cerebral hemorrhage, and heart disease, are primarily disorders of middle adult life and old age, and the increase in deaths from these causes is largely due to the aging of the population. These are also diseases of the degenerative type. While a satisfying decline in the death rate has been made in the infectious diseases, it is possible that we are failing in our efforts to control degenerative disorders. The increase in deaths due to diseases of middle life or past is offset, however, by the improvement in infant mortality which declined 15 per cent during the period 1934–1938.

Although great advances have been made in organized public health, there are many urgent problems remaining to be solved. Since morbidity and mortality rates are purely quantitative measures of health, a group may evidence a low incidence of disease and death and yet, by qualitative measures, possess a relatively small degree of health. While

morbidity and mortality rates in the general population have never been lower than at the present time, recent statistics relating to the medical examination of registrants for selective service indicate an alarming state of health in that portion of the male population between the ages of twenty-one and thirty-six years. Up to about November 1, 1941, slightly more than two million men were examined for induction in the army. Approximately 50 per cent of this group was disqualified for military service for physical, mental, or educational reasons. Of the one million men rejected, nine hundred thousand were unacceptable for physical and mental reasons and the remaining one hundred thousand because of the lack of educational attainments equivalent to the fourth grade in school. This high rate of rejection is considerably greater than that in World War I and is of grave concern primarily because the very existence of this country is now in the hands of its young manhood. As in the case of previous wars, dental defects and visual deficiencies are the principal causes of rejection. While little of value is to be gained from a comparative study of medical examination statistics due to the variables involved, it is significant that little has been accomplished since the last war in providing more effective measures in caring for teeth, eyes, and other disabling defects. Because health deficiencies present a rather constant statistical pattern, persons familiar with health conditions among school children could have predicted fifteen years ago the probable health status of present-day draftees. Since, however, little organized effort has been made to remedy these disabling health deficiencies, the nation is now deprived of valuable manpower in times of its greatest need.

While the high rate of rejection of draftees is deplorable, there is yet another element in the situation which is seriously

hampering our war effort. Because of the lack of strength, endurance, and qualities of aggression in the men entering the service it has become necessary to retard the military training program in order to build in these men sufficient physical stamina for them to withstand the rigors of training. Modern methods of warfare demand the utmost in aggressiveness and total fitness, and it is apparent that this nation cannot survive if its functions are frustrated by a people not totally fit to operate effectively all branches of the service, both at home and on the fighting fronts. The contribution of vigorous, competitive athletic sports to a successful war effort is generally recognized. The program of competitive athletics, however, reaches only a relatively small percentage of the total population. To meet the problem school programs of physical education should be extended to include all students and considerably intensified in terms of requirements. Community programs of physical education are of equal importance and therefore need to be expanded to reach all ages and classes of the population. The unfavorable health and physical condition of men in the age group which normally should be expected to furnish the healthiest and strongest men discloses the lack of an adequate public health program looking toward the conservation of our human resources. A program of human engineering needs to be placed in operation immediately in order to meet the present emergency, and to insure against a similar situation in the years to come. The ingenuity of the scientist and engineer may combine to create the machinery of war; men, however, are not so easily moulded.

In times of war many factors combine to increase both in number and degree the problems confronting the field of public health; the present war is no exception. The concentration of troops in localities inadequately prepared to

care for men on leave, the exodus of medical doctors into the armed forces, and the hordes of itinerant workers on defense projects have created problems of medical care, sanitation, food supply and preservation, housing, schooling, and the control of various contagious diseases. The incidence of venereal diseases, for example, is sharply on the increase and one of the most difficult problems of military authorities and public health officers is to find a way to prevent the destructive forces of these diseases. Newer methods of treatment employing the sulfonamides and fever therapy are proving particularly effective in the control of venereal diseases. New laws and a stricter enforcement of those already in existence are aiding in the solution of the problem. The May Act which was passed by Congress and approved by the President in July, 1941, gives the most promise of legal control. This Act makes prostitution a federal offense in areas adjacent to military or naval establishments. In spite of all the efforts toward the prevention of the venereal diseases, however, they continue to flourish. While they are destructive in terms of time lost and possible disabling after-effects, their chief harm lies in the degrading mental and moral effects on the young manhood and womanhood of the nation.

Mental disease constitutes one of the gravest problems confronting the field of public health. On the upgrade in normal times, the incidence of mental disease increases sharply in times of national unrest. More than one-quarter of the total hospital bill of the nation is spent in the hospitalization of mental patients. The magnitude of the problem cannot be measured in terms of numbers admitted to hospitals, however, for it is much broader than the mere provision of care and treatment of those with incapacitating psychoses. Aside from these unfortunates, and in addition to the feeble-minded, the epileptic, and the criminally in-

sane, there are a vast number of borderline cases, and thousands of sufferers from mental disease who are treated outside of institutions, or who remain undiscovered and untreated. Added to this total is the number of maladjusted, unhappy, and disillusioned individuals who go to make up the complaining, faultfinding, and disgruntled element in society. It is this group which helps to fill our jails and supply the divorce courts with material from which to fashion broken homes. There is perhaps no field of public health which is more in need of study and constructive action than that of mental disease.

It has often been said that public health can be purchased. This statement may be true to the extent that it refers to the purchase of physical equipment necessary to produce sanitary living conditions; when applied to the realm of individual health knowledge and health practice, however, it cannot be substantiated. Since health is more than mere freedom from disease, much of the success of a scientific program of public health depends on the understanding and appreciation of the problems involved by those for whom the program was designed. These are matters concerning formal education, since the enlightenment of the individual is the only means of securing an enlightened public. It is in health education, therefore, that the school can make its greatest contribution to public health. Because health knowledge must be translated in terms of health practice, the school has a unique opportunity to improve the health habits of a large portion of the total population. A comprehensive school health program includes the areas of health appraisal, healthful living, and health instruction. Also included are extensive programs of physical education, recreation, and safety education. Through the activities of these areas of education, health and safety habits, health knowledge and

ideals, and healthy bodies may be developed. It is only through the forces of education that truth can replace superstition and the general public thus be enabled to distinguish between fact and fiction in all matters pertaining to health.

Although the local, state, and federal governments are spending great sums of money on programs of public health, many of the most pressing problems in this field arise out of the impoverishment of persons in the low income and underprivileged groups. In 1935–36, in the United States "14 per cent of all families (of two or more persons) received less than $500 during the year; 42 per cent received less than $1000; 65 per cent, less than $1500; and 87 per cent less than $2500."[1] While these figures must be revised upward for the year 1943, it is still safe to say that many families and individuals do not have the necessary financial resources to purchase adequate medical and dental services, nor are they able to benefit from group hospital insurance plans or similar devices. Because of the close alliance between organized medicine and the field of public health, most of the objectives of the two fields are similar and therefore overlapping. There is, however, one objective on which the two fields apparently disagree. This objective relates to the problem of providing medical service for individual members of society who are unable to provide for it themselves. According to the tenets of public health any ordinary sickness becomes a public health problem if systematized public action is necessary for providing medical services. Rendition of medical care has been accepted as a responsibility of society or government in cases of the insane, lepers, tuberculosis, inmates of public institutions, the pauper sick, and members of our armed forces. If, however, society or

[1] *Education and Economic Well-Being in American Democracy* (Washington, D. C.: Educational Policies Commission, 1940), p. 138.

government provides high grade medical care at low cost for the sick individual, then the private practitioner is likely to suffer. The high cost of medical education together with the expensive diagnostic and therapeutic services required of the private physician make it almost prohibitive for him to provide low cost medical service. The solution of this highly controversial issue is not immediately at hand; certainly the problem is one of increasing sociological importance. If the present trend in government continues, however, it is likely that we shall see a greater rather than a lesser number of instances of social or state medicine.

Today many of the scientific forces of this technological age are directed toward the creation of the machines of war. Scientific research in medicine and public health must be continued, however, since the demands of war increase the need for more exact knowledge in these areas. For this purpose those foundations, professional organizations, life insurance companies, and commercial groups, which have made valuable contributions to the cause of public health in the past, should increase rather than decrease their support during the war period. Likewise, increased aid should be forthcoming from federal, state, and local governments for purposes of research and health promotion work. Institutions engaged in medical education should expand their courses of study to include instruction for all medical students in public health practices and school health programs. There is a great need in the field of public health for scientifically educated leadership. In order to fill this need the number of medical schools preparing students for professional careers in this field should be increased. Legal methods for curbing spurious advertising should be improved and there should be a more rigid enforcement of already existing local, state, and federal laws affecting the

health of the public. Greater efforts should be expended toward the extension of public health services to rural communities and toward making existing services equally available to all persons. The school program of health and physical education needs to be improved and expanded, and a more equitable plan devised to provide medical and dental care for those persons in the community who are financially unable to purchase these services themselves. It is only through these means that we can hope to create a public health program of the quality and scope necessary to solve the health problems arising out of the war and adequate for the peace which is to follow. HARRY A. SCOTT.

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III

THE STRUCTURE OF THE UNIVERSE

IT MAY SEEM, at first sight, presumptuous to attempt the discussion, in one hour or less, of such a comprehensive topic as the structure of the universe. Actually the subject is not as big as it sounds. There are, in one sense, as many universes as there are individuals; but the universe in this personal sense will be ruled out of the present discussion. A tremendous simplification is at once achieved when we limit our topic to the physical universe. We now inquire, what is the physical universe?

Eddington has defined it as the "theme of a specified body of knowledge, just as Mr. Pickwick might be defined as the hero of a specified novel." Such a definition emphasizes the epistemological point of view and therefore it suffers from lack of definiteness and simplicity. There is beautiful directness and decisiveness in the attitude of the mathematician who wrote an equation on one line in one of his published papers and said, "This equation contains everything we know about the physical universe." The conciseness of the language of mathematics is probably nowhere better exemplified than in this equation. On the other hand, the universe, if it can be described in terms of mathematical symbols and with one equation, may not seem like such a big subject after all.

To the physicist, matter, space, and time exist outside the human mind. The physical universe is an objective, dynamic arrangement of all matter, space, and time. In discussing the

structure of the universe we merely attempt to describe some of the features of this arrangement.

Before beginning such a description it seems necessary to indicate just how it is related to human welfare—since the general title of this series of lectures is "Science and Human Welfare." I am venturing to interpret the phrase "human welfare" in the broadest possible sense. There are many types of scientific investigation which do not appear to have any direct bearing on the pleasures or pains of the human race. The discovery of the planet Pluto cannot be said to have done very much towards raising the sum total of human welfare, in the ordinary sense. But in the broadest sense, it may be said that the welfare of a nation is closely tied up with the capacity of that nation for untiring search after truth. Intellectual unrest, intellectual curiosity is, we like to think, essential to the true growth and development of a people. A dairy company advertises that its milk comes from contented cows. A rival company is perhaps more progressive in its views when it advertises that its cows are not contented—they are always trying to do better.

The thesis is, then, that the pursuit of pure knowledge is indicative of a healthy national mind; that full development of intellectual activity, whether it be in the matter of investigating the stars or in building a better radio, is essential to the true welfare of a nation. The Russians asked a captured Nazi why he came into their country. He replied, "I am just a little man, I do what the Führer says." A nation is facing tragedy when free speculation is discouraged, when science is devoted solely to control of men and machines and to the production of a workable mass of "little men."

To begin this discussion of matter, space, and time we will try first to systematize our ideas of space, or size, in relation to matter. Imagine a long, horizontal line drawn so

as to represent "the x-axis." Let all objects in the universe be placed along this line in the order of their sizes. The smallest objects will be placed near the beginning of the line,

FIG. 1

at its left end. Larger and larger objects will be placed farther and farther to the right. We next divide the line into two parts by a vertical line. All objects to the left of this vertical line are too small to be seen with the naked eye, so this region is called the *microscopic* region. In it are placed different kinds of particles such as molecules, atoms, the proton, the neutron, the mesotron, the electron, positron, and neutrino. These particles are placed nearer and nearer to the origin of the line as they become smaller and smaller. It is worth noting that nature seems not to have given us anything smaller than the electron, in spite of the fact that there is plenty of room for particles between the electron and the origin of the line.

To the right of the vertical dividing line we place all objects large enough to be seen with the naked eye. This region is called the *macroscopic* region. We might put in here, stones, mountain, earth, solar system, spiral nebulae. The farther end of the macroscopic region may be given a special sub-title, the *astronomical* region.

We have arranged here various matter elements in a certain spatial relationship. The time concept is involved because this is an arrangement which may be correct only at one instant of time. It is possible that the position of some of these entities on the line is constantly changing. When an

electron gets into rapid motion its mass is changed a little and it shortens one of its dimensions. It thus shifts its position on the line slightly to the left whenever it has a high velocity. The solar system may be slowly running down so that the planets gradually approach the sun. If this is the case the position of the solar system on the line is slowly shifting to the left.

Certain segments of this line have occupied the attention of various specialists. Astronomers deal with everything listed to the right of earth. Thousands of specialists work on the section from earth to atom. Physicists in recent years have concentrated intensively on the segment from atom to zero. The discovery of the positron, the neutron, the mesotron, within the last decade, has opened up a most fruitful field of research in physics. In this region, forever beyond the reach of the human eye, is probably contained most of the mystery of the entire universe. As K. K. Darrow has expressed it, "This field is unique in modern physics for the minuteness of the phenomena, the delicacy of the observations, the adventurous excursions of the observers, the subtlety of the analysis, and the grandeur of the inferences."

It is not too much to say that if some American physicist could only make the right kind of discovery in this domain our entire oil and coal industries would become more or less obsolete and World War II would be won in a matter of days. It should also be said that such a discovery is possible but not probable.

Returning now to our linear layout for the universe we may note that everything to the right of proton is constructed out of the material included in the range from proton to zero. All matter in the universe exists in the form of bunches or aggregates of smaller parts. Protons, neutrons, electrons bunch to form atoms; atoms group into molecules; molecules

The Mount Wilson Observatory

FIG. 2. The spiral nebula M 51 in Canes Venatici.

group into stones and mountains; stones and mountains form the earth. In the astronomical field, planets group about the sun to form the solar system—a solar system which in the astronomical field is remarkably like the atom in the microscopic field.

The important unit of structure in the astronomical field is a sun. Practically all of the stars which we can see on a clear night are distant suns, much like our own, although it is thought that only an extremely small fraction of these suns have planets around them like our own.

All of these suns which can be recognized distinctly are grouped in a sort of flattened, disk-like bunch which is whirling in empty space. Our own sun and planetary system is a member of this group, being located about 30,000 light-years[1] distant from the center, or hub, of this gigantic disk. When we look into space along the plane of the disk the stars seem to be distributed very densely. We see the milky way. This bunch of suns is called a spiral nebula. It is sometimes called a galaxy, or an island universe. The word "universe" in this sense has a restricted meaning because our island universe is not the only one in existence. There are millions of others distributed throughout space as far as our most powerful telescopes have been able to penetrate.

The nebulae are by no means recent discoveries. Sir William Herschel, 150 years ago, suspected that they were distant groups of stars. The philosopher Kant believed that they were "systems of many stars, whose distance presents them in such a narrow space that the light which is individually imperceptible from each of them, reaches us, on account of their immense multitude, in a uniform pale glimmer." They have been described as looking like "candle-

[1]A light-year is the distance which light travels in one year. It is approximately 6,000,000,000,000 miles.

light seen through horn." A rough diagram, not drawn to scale, is given in Fig. 3 to indicate the total extent of the

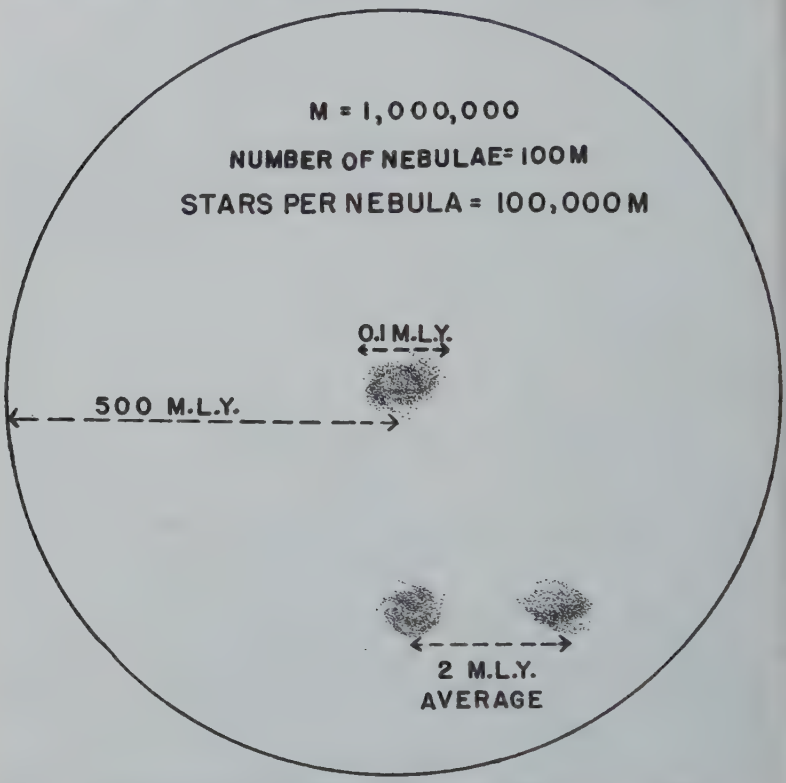

Fig. 3. Sphere of view of the 100-inch telescope. Distances are in light years, L.Y., and the diagram is not to scale. Our earth is about 30,000 L.Y. away from the center of the central nebula above.

entire universe which has been observed, up to the present, with our most powerful telescopes.

We might now indicate on the linear layout of Fig. 1 the approximate size of the largest bunch of matter, the spiral nebula, as 100,000 light-years. Also we might speculate as to the possibility of nebulae themselves forming still larger groups. Extensive surveys have been made by the astrono-

mers at Harvard and Mount Wilson, of the distribution in space of the nebulae, and there is, indeed, evidence of grouping of nebulae. It is legitimate to add another bunch of matter to the line layout—the super-nebula, or super-galaxy.

The super-galaxy is the largest known aggregation of matter in the universe. Its diameter may be of the order of a million light-years. At least that is the estimate made by Harlow Shapley of the diameter of the group of nebulae in which our own is located. Our local group contains perhaps 15 or 20 nebula, but in some super-galaxies there are hundreds of members.

So far, then, our picture of the universe reveals a granular, or atomic structure. We start near the zero point of size, with a particle of definite size. A fundamental law of attraction operates to cause the small particles to group together to form larger particles, these larger particles again group to form still larger particles, and so on until we reach the limit of observation, the enormous super-galaxy. We are unable to put a stop at the right hand end of our line, as we have done at the left end. Space may go on into infinity—possibly matter may go on bunching up into larger and larger aggregates with no limit as to the ultimate size of any final bunch, because there may never be any final bunch. Speculations of this kind may be interesting but they are not of much significance, otherwise, because they take us outside the realm of possible human experience.

It seems probable that in detecting the super-galaxy man has reached the limits of observation in his probing of the depths of space. The new 200-inch telescope will be doing a fine job in helping to chart and analyze these enormous groups of matter.

The line diagram of the universe, limited at one end by the electron, at the other by the super-galaxy, has given a

rather simple picture in terms of two variables, space and matter. The third variable, time, must now be considered. We have to consider the relationship between the various units of our structure as this relationship may change from time to time. Newton's Law of Universal Gravitation says that every particle of matter in the universe attracts every other particle. If forces of attraction cause matter to bunch up into aggregates of various sizes why may not the various bunches themselves start coming together until eventually there results just one large, static bunch of matter floating quietly in an infinity of space? Such an end result seems logical, but it cannot happen until the kinetic energy of matter, the energy of motion, has been converted into radiation and transferred to infinity. Such a transfer of energy appears, in fact, to be going on.

A study of the motions of the various aggregates may be expected to throw some light on this question. We start with the smallest particles, electrons, for example. In addition to random motions caused by collisions with other particles, all electrons are supposed to spin. They may be thought of as being like tops which never run down. When an electron helps to form an atom, in addition to spinning it also revolves about the nucleus, just as the earth revolves about the sun. The aggregations of matter between atom and earth on the diagram of Fig. 1 may have various kinds of motion but when earth is reached we again have the spin about an axis and the revolution about the sun. Our sun, together with all the other suns in its group, forms a nebula which spins with high speed about a central axis. The spin velocity is very high, but the size of our nebula is so great that it takes about two million centuries for it to make one revolution. As Shapley puts it, this is the time required to "click off one cosmic year."

The motion of the super-nebula is not known in accurate detail. It is possible that some sort of gigantic spin is present here also, but so far such a spin has not been detected. Instead, a very surprising sort of motion has been discovered, a motion which is just contrary to what we expect if matter is to agglomerate into one big bunch. The super-nebulae appear to be receding from us. The super-nebula to which our galaxy belongs maintains its fixed dimensions, and behaves more or less as a unit, but all the other super-nebulae appear to be flying away from ours with high speeds. The farther away from us they are, the faster they seem to recede. There seems to be no good way of explaining such a phenomenon. One might assume that a primeval explosion started all matter out in all directions from an original concentration, but there are serious difficulties involved in such a theory.

The whole question of the expanding universe is definitely controversial. The consequences of accepting or rejecting the theory are so great that it will be worth while to review briefly the evidence.

Suppose the lights of a very distant city are observed at night through a telescope. The various spots of light all look much alike. However, they are not all the same in character. Some may be caused by incandescent lamps, some by neon signs, some, perhaps, may be due to the newer type of yellow sodium lamp used for illuminating highways.

We now put a glass prism in front of the telescope objective. The telescope must be deviated sideways, if we are to see the city through the prism and the telescope. When we do see it, each spot of light appears to be smeared out into a band of color. The colors present in each spot of light are separated and spread out and we can see just what colors are present in the light from each source. The neon signs are

characterized by definite colors in the orange and red; the sodium lamps can be recognized by the fact that only one color, yellow, is visible.

If we were to photograph the lights of an enormous city from an enormous distance the whole city would appear as a small, luminous spot. The prism would smear out the separate lights of which the spot is composed, but they would all be superposed in a single smeared spot for the whole city. However, if there were a large number of sodium lamps one point in the smear would be brighter than the rest because there would be an excess of the yellow sodium light.

A nebula, consisting of millions of suns a long distance away, behaves like our hypothetical city except for one small difference. Light from a sun has *dark*, absorption lines or bands, from which color is missing as a result of absorption in the sun's atmosphere. There is a dark line in the spectrum of our own sun, corresponding to absorption of hydrogen in the sun's atmosphere. This dark line always appears at the same place in the spectrum no matter what kind of a source, and always means that hydrogen is present. Dark lines appear in the nearer nebulae about where they should be in the spectrum. For the more distant nebulae, however, they are shifted towards the red end of the spectrum.

There is only one known explanation for such a shift of a spectral line. If the source is moving away from an observer the light received appears redder than when the source is stationary. This phenomenon is called the Doppler effect. It is a matter of common experience in the field of sound. The pitch of an automobile horn is lowered as the horn passes rapidly by an observer and recedes from him.

The photographs of the nebulae show that the hydrogen absorption line is shifted farther and farther away from the normal position as the pictures go to more and more distant

nebulae. The amount of the shift gives the velocity of recession. Many nebulae have been observed and the conclusion is reached that for every million of light-years distance from the earth the velocity of recession is increased by about 100 miles per second. The farthest nebulae observed are flying away from us with a speed of about 25,000 miles per second.

It is well to weigh critically the evidence for results like these. As regards estimates of nebular distances the methods used by astronomers seem entirely adequate. In the nearest nebula individual stars can be seen. Some of these stars fluctuate in brightness with a period of 5⅓ days. Similar stars, known as Cepheid variables, are found in our own nebula and the distances of a few of them have been determined by ordinary engineering methods. It is found that these stars are all of about the same size, so that if one Cepheid variable is much fainter than another its faintness may be attributed solely to its greater distance. The distance of the nearest nebula can thus be determined with considerable accuracy by comparing the brightness of one of its Cepheid variables with the brightness of a similar star in our own galaxy—a star whose distance has been measured by reliable methods. Having a good estimate of the distance of one nebula it is legitimate to infer that other nebula of the same type are fainter and smaller only because they are farther away. It is thus possible to estimate their distances. The results of these estimates might give occasional large errors, but when a great number of observations are made the individual errors must average out fairly well.

As regards the shift of the absorption line towards the red, a good many attempts have been made to explain it in some other way than by the Doppler effect. So far, all of these attempts have failed or encountered logical difficulties. During the last few years, however, certain evidence has accumu-

lated which has brought about a paradoxical situation in the theory of the expanding universe. There are some very serious objections to the theory. First, let us suppose that our explosion hypothesis is more or less in accord with the facts. After all, if the nebulae are now observed to be scattering they must at some previous time have been more closely bunched. It is not difficult to calculate how long ago it was when the nebulae were all together and touching each other. We know how far away they are now, we know how fast they are receding, and how their velocity of recession varies with the distance from us. These data enable us to calculate the time when they must have started. According to Hubble, after all corrections have been made this starting time was about 1000 million years ago. Unfortunately this is only a fraction of the age of the earth—indeed there is evidence that life actually existed on earth that long ago. It is difficult to see how our earth could exist in its present form at a time when all matter in the universe was assembled and ready for a cosmic blowout of such tremendous proportions.

So much for objection number one. The second objection arises as follows. When a source of light moves away from an observer there are two effects produced. The first, the Doppler effect, has been mentioned as a change of color, a reddening of the light. A second effect is a decrease of brightness, known as the "dimming factor." It is easy to see why a light should appear to be dimmer when the source moves away from the observer. Suppose a stationary machine gun is firing bullets at a fixed target at the rate of five per second. Then every second five bullets hit the target. However, if the gun is moving away from the target, still firing five shots a second, there will not be five bullets hitting every second. The bullet discharged from the gun at the end of a given second will have had to traverse a greater distance than the

bullet which was fired at the beginning of the second, so it will take a longer time to reach the target. Perhaps only four bullets will hit the target in one second. The extra bullet has gone to fill the extra space in the bullet stream—the extra space created by the recession of the gun. The case of a light source is exactly analogous.

Now in estimating the distance of a nebula its brightness is taken as a criterion of the distance. The question arises as to whether the dimming factor should be applied when making the distance estimates. If the nebulae are actually moving away from us then the factor must certainly be applied. If the reddening of the light is not caused by a velocity of recession then the dimming factor must not be applied. With such tremendous speeds of recession this factor makes quite a big difference in results.

The following discussion is very largely quoted from the annual Sigma Xi lecture delivered in December, 1941, at Dallas by E. P. Hubble of the Mount Wilson Observatory. Dr. Hubble is one of the world's foremost authorities on the subject of nebulae.

Let us first suppose that the reddening of the light is *not* caused by a velocity of recession. It may be due to some hitherto undiscovered and unknown phenomenon. We can then estimate distances without any dimming factor and a survey can be made to find out how the nebulae are distributed throughout the region of space within our present range of view. Such surveys have been made at Mount Wilson and Mount Hamilton, out to a distance of 420 million light-years. Data have also been obtained and analyzed at Harvard, and the net result indicates a fairly uniform distribution of nebulae throughout the observable regions of space. There are, on the average, just as many per unit volume at great distances as in the immediate neighborhood of our own group.

This result is intellectually very satisfactory. In fact, it agrees with a fundamental principle of cosmological theory, a principle which has been postulated by theorists for no other reason than its appeal to our sense of order and the fitness of things. This principle states that the universe, on a grand scale, will appear much the same from whatever position in space it may be viewed, or explored. This principle of cosmology is satisfied, therefore, if the nebulae are not assumed to be receding.

We next investigate the consequences of assuming the red shift to be due to a real velocity of recession of the nebulae. The dimming factor must now be applied in estimating distances, with the result that the most distant cluster is actually about 13 per cent fainter than it would be if it were stationary. The scale of distances is thus altered, so that when we make our space survey to find out how the nebulae are distributed it turns out that they are no longer scattered uniformly. The number per unit volume increases steadily with their distance away from us. Here is a result which is intellectually very disquieting. The cosmological principle of no favored position is violated. We might be willing to accept this violation if it went the other way, that is, if the density of nebulae decreased with distance. Then we would conclude, very happily, that we had discovered another super-super-galaxy, another big matter bunch to put out on the right hand end of our linear layout. No such interpretation can be given when the nebulae are found not to thin out at big distances, but actually to become more dense in numbers.

It may seen obvious to the layman that we ought to discard the idea of an expanding universe. It makes us worry about the short time which has elapsed since the original cosmic explosion occurred; it bothers us with an increasing density of matter as we proceed farther and farther into

the depths of space; and the only evidence we have to go on is a series of pictures, rather hazy, smeary pictures, in fact, with a light patch shifted too far to one side.

The physicist and the astronomer, unfortunately, cannot treat these fuzzy pictures in such a cavalier manner. There is no denying the existence of the shifted light patch in the pictures, hazy though it may be. There is no denying the fact that all such similar shifts of color have been explained satisfactorily by the Doppler effect and by the Doppler effect alone. One is reminded of the saying of the old colored man, whose years of experience had developed a certain ripe philosophy of life. "It ain't so much what you don't know that gets you into trouble, it's what you do know and ain't so!"

There are several ways, more or less unsatisfactory, of escaping from the dilemma of the expanding universe. The first way is not a good way, but like other escapist philosophies it must be considered and estimated for what it is worth. It involves spatial curvature.

The idea of curved space is now quite a familiar idea to most people. Eddington, Jeans, Einstein, and others have written books for popular consumption and the sales have been very gratifying. Even the pulp magazines do not hesitate to invoke the fourth dimension as a mode of escape for the hero or the villain. A simple way of approaching the concept of spatial curvature is as follows. Think of a straight line along one dimension. Given a second dimension at right angles to the first, then we have the possibility of curving the line into the second dimension. Think of a plane surface, like a sheet of paper flat on a desk. Given a third dimension, at right angles to the desk, we have the possibility of curving the paper sheet into this third dimension. Think of a solid filling three dimensions. Give a fourth dimension at right angles to the other three, we then have a possibility of

curving the solid into the fourth dimension. It is only because we have three-dimensional minds that we cannot see this fourth dimension.

A mathematician may speak of space itself as being curved without reference to any solid matter in it. For example, consider the earth to be perfectly smooth. If we were two-dimensional creatures instead of being three-dimensional, we might draw a big circle on the earth's surface, measure its diameter and its circumference, and then find that the circumference was not equal to π times the diameter. We would not know that the circle was not flat (since we are assumed to be two-dimensional), but we could certainly infer a curvature of our flat space and even determine its radius if we knew enough about ordinary Euclidean geometry, which would work pretty well for small circles on the earth's surface.

The mathematical description of the universe to which allusion was made at the beginning of the lecture involved curving of three-dimensional space in somewhat the same fashion as described above for the two-dimensional space. If space actually is curved in this way our ordinary solid geometry, Euclidean geometry, would not be quite correct. In order to find out whether it is correct, measurements of certain kinds must be made. For example, if a negative parallax could ever be observed for a single star, a spherically curved space would be implied. The mathematician Schwarzschild, a good many years ago, attempted to find what curvature of space would be possible according to certain types of non-Euclidean geometry. In dealing with these geometries he said, "One there finds oneself, if one but will, in a geometrical fairyland, but the beauty of this fairy tale is that one does not know but that it may come true."

Schwarzschild's results need not be considered here be-

cause his data were limited and because we have at present more detailed modes of procedure than he used. There are at least two mathematicians who have achieved the unique distinction of having a universe named after them. They are Einstein, and a Dutchman named de Sitter. Both universes are non-Euclidean and the Einstein universe appears to be the more popular. The curvature of the Einstein universe is determined by the amount of matter in it, and if it is not a static universe, by certain other factors. A chunk of matter produces quite a large local curvature, which is evidenced to us by what we call gravitational attraction.

This universe is not infinite in extent. It is a closed universe with a finite volume but having no boundaries, just as the surface of a sphere is a closed surface of finite area yet has no bounding edges. In this universe one might expect to see a star in two directions, first by looking directly at it, second, by looking in the exactly opposite direction at light rays which have gone completely around the circuit of the universe in the opposite direction. Star images have not been seen in this way, possibly because their light is too faint after the long trip around the universe. There is also the possibility that the theory is wrong. It has, however, been seriously suggested that two very faint nebulae, observed in a certain direction, may actually be the backs of two of our nearest neighbors, as seen the long way around.

The theory of a finite, closed universe is very attractive in many respects. We may again use the term "intellectually satisfactory" in this connection, largely because this universe can be given a concise mathematical description and in terms that explain the gravitational effects of matter. There is also, in many individuals, a definite repugnance to the idea of infinite space. In discussing the stars Kant, in 1755, says, "There is here no end, but an abyss of real

immensity in presence of which all the capability of human conception sinks exhausted." The finite mind likes to set up a blank wall somewhere, in order to end it all. It is probably intellectually satisfactory to know that one can start out in imagination and not have to get farther away forever and ever, but will eventually get back to the good, old, familiar region of the starting point.

With this picture of a finite, closed universe in mind we may now return to the question regarding the nebulae. Why should they appear to be crowded together at great distances from us? The answer might be that the curvature of space appears to make them crowd into smaller and smaller volumes as their distance increases. If this is true it is possible to calculate what radius of curvature of the universe would give the observed apparent crowding of the nebulae at great distances. Such calculations have been made and the universe turns out to be remarkably small. In fact, it is so small that our largest telescopes would allow us to see about one-sixth of the way around it. This small universe is required in order to explain the apparent non-uniform distribution of the nebulae. However, if we calculate the radius of the universe in this way we are obliged to have only a certain amount of matter in it, since, according to Einstein, the radius is determined by this total amount of matter. Hubble has made surveys to find out whether the observed amount of matter will fit in with the radius as determined above. He estimates that if all observable stars and nebulae were smeared out uniformly there would be a maximum of about one hydrogen atom per cubic meter. This density of matter is far too small. In other words, there is not enough matter in the universe to give it a curvature great enough to spread out the nebulae uniformly. The theory of curvature of space has, therefore, failed to resolve the problem.

Another way out of the dilemma is to suppose that the observations of the astronomers are in error. Here is what Hubble has to say. "These questions have been carefully reexamined during the past few years. Various minor revisions have been made, but the end results remain substantially unchanged. By the usual criteria of probable errors the data seem to be sufficiently consistent for their purpose. Nevertheless, the operations are delicate, and the most significant data are found near the limits of the greatest telescopes. Under such conditions it is always possible that results may be affected by hidden systematic errors. Although no suggestion of such errors has been found, the possibility will persist until investigations can be repeated with improved techniques and more powerful telescopes. Ultimately the problem should be settled beyond question by the 200-inch reflector destined for Palomar." This telescope will have about twice the range of the best one now in use. Work on it has been stopped by the war, so it is impossible to predict just how soon it can be put to work on this problem.

The last way which may be suggested for escaping from the dilemma is to suppose that in the region of astronomical magnitudes some new principle of nature is operative—some principle which we have not yet discovered in the ordinary macroscopic field. Such a principle would have to free us from the necessity of using the Doppler effect, and we would no longer have to say that experimental observation shows the universe to be expanding. This new principle would, therefore, have to explain why the light from nebulae gets redder and redder as it travels greater and greater distances. Perhaps light which has been travelling for 100 million years in a straight line exhibits its senility by a decrease in the frequency of its vibrations. We do not know of any possible

reason such as this why old light should be different in any way from new light. The only place from which we can get really old light is from the distant nebulae, so our chances of establishing by experiment a new principle of physics like this seems at present to be involved in a vicious circle from which there is no escape.

It appears, therefore, that our knowledge of the structure of the universe at the limits of the astronomical range is unsatisfactory. We have to recognize that there are discrepancies between theory and experimental observations. Hubble says that "a choice is presented, as once before in the days of Copernicus, between a strangely small, finite universe, and a sensibly infinite universe plus a new principle of nature."

We may now go back once more for a comprehensive view of what we have called the linear layout of the universe in Fig. 1. The three components, or variables, were assumed quite simply to be space, matter, and time. At the right hand end of the scale we have become embroiled in some rather questionable speculations regarding the nature of space and the behavior of light. In this region, where a light-year is the unit of distance and a nebula the unit of mass, we have good reason for suspecting that the mechanics of the universe cannot be described or explained in such a simple way as in the region of miles and mountains.

Peculiarly enough, if we go from the enormously great region to the extremely small region, the region of the electron and the positron, we encounter similar difficulties. You will remember that Darrow characterized the microscopic region as unique because "of the adventurous excursions of the observers," and "the grandeur of the inferences." One or two of these inferences and excursions may be cited here, and it will appear that the simple concepts of space and

matter have suffered in the microscopic field in much the same way that they have suffered in the astronomical field. As the result of investigations in the field of the small particles it has become necessary to broaden our ideas as to the nature of matter. Cloud chamber pictures have allowed us practically to see two particles of matter created in space from the energy contained in radiation.

The thing that happens is that a photon, an atom of radiant energy travelling with the speed of light, somehow gets itself into a peculiar situation in a microscopic field of some kind. The result is that the photon changes into two particles with electric charges, a positron and an electron.

In the macroscopic size range an equivalent phenomenon would be for a quantity of sunshine, passing by an iron ball, to change suddenly into a couple of buckshot.

Needless to say, no one has ever seen anything like this happen. It is only when sizes become so small as to prevent direct observation that the event occurs. We may well say that something peculiar is going on in the microscopic field. Something is happening which is foreign to our ordinary experience.

Technically this phenomenon is known as pair production by a photon. The reverse process, conversion of matter into radiation, can occur when an electron and a positron come together under proper conditions. They disappear and two photons of radiation are shot out with the speed of light in opposite directions.

Matter and energy can now be thought of as practically synonymous. It thus becomes possible to make certain grand inferences with the object of saving the universe from running down. Millions of suns are slowly but surely converting their matter and their energy into radiation and this radiation is constantly escaping into infinity. Perhaps, somewhere in space, radiation may be changed back into matter. Per-

haps the universe is engaged in a reversible cycle, instead of an irreversible one, as is commonly supposed.

As an illustration of what Darrow calls an "adventurous excursion" of an observer we may take the Dirac theory of the positron. Dirac is a brilliant young Englishman, a mathematician who has demonstrated a high degree of daring and originality in his handling of theoretical physics.

His theory of the positron starts out with two peculiar assumptions. First a particle may have a negative kinetic energy. Second, all space is filled with particles of negative kinetic energy. There is a distribution of electrons of infinite density everywhere in the world. A perfect vacuum is a region where all the states of positive energy are unoccupied and all those of negative energy are occupied.

When an electron, by some means or other, gets knocked out of this state of negative energy into a state of positive energy, it is observed as an ordinary electron; the hole which was left is a positron. This hole may wander around for a short time, but there are so many more electrons in the universe than holes that it is not long before some electron drops into the hole and both hole and electron disappear from the view of normal people. The very short life of the positron is thus explained, as is also the phenomenon of pair production and the conversion of matter into radiation.

I have given this hasty outline of the theory, not that I expect anyone to understand it—it is hardly to be expected that negative energy can be understood—but because it illustrates the lengths to which a theorist has to go in creating physical explanations in this field. In the microscopic range of sizes a quite perfect explanation of things is given by a specialized type of mathematics called wave mechanics. It is only when this mathematical symbolism is explained in terms of physical symbolism that we call it an adventurous

excursion. Dirac showed great courage in even trying to give a physical picture of his mathematical theory. The fact is that in the microscopic field things may behave in a way entirely foreign to the way in which we have always seen large objects behave, hence they cannot be explained in the old familiar ways.

There is in most people a strong tendency to label as "bunk" that which is not understood. This tendency is, on the whole, a healthy one. Skepticism is preferable to credulity if one is thinking in terms of the struggle for existence. The radio-listeners who believe all the remarkable statements made about cough-syrups, breakfast foods, cigarettes, etc., must certainly be struggling very hard for existence. However, skepticism based upon a lack of understanding is a dangerous attitude of mind. Professor P. W. Bridgman of Harvard, has this to say in his book, *The Logic of Modern Physics:*

"It is difficult to conceive anything more scientifically bigoted than to postulate that all possible experience conforms to the same type as that with which we are already familiar, and therefore to demand that explanations use only elements familiar in everyday experience. Such an attitude bespeaks an unimaginativeness, a mental obtuseness and obstinacy which might be expected to have exhausted their pragmatic justification at a lower plane of mental activity."

The explanation of microscopic phenomena, then, utilizes concepts which are not familiar to everyday experience. For that reason the microscopic tends to undermine any smug complacency we may have regarding our knowledge of nature and the universe. Take, for example, the Heisenberg uncertainty principle. This principle states that we can never know accurately both the position and the velocity of a small particle. It is easy to see why this is true. We can see

the small particle because light has bounced off of it into our eye. We see it in the direction from which the light bounced.

But the light, in bouncing from the particle, must have given it a push so that either its position or its velocity will have been changed by the mere fact that light must be used to observe it. By the time the light photon gets to the eye of the observer the particle will not be at exactly the spot from which the photon appeared to bounce.

This uncertainty principle has been given an exact mathematical formulation. It turns out that if the position of an electron is known to within 0.004 inch then the speed of its motion is uncertain to within about 3 feet per second—the speed of a slow walk.

The tendency, at first, is to consider this as rather a superficial principle. I can easily imagine a particle to have both position and momentum simultaneously; why bother so much about a mechanism for determining them? However, a thorough study of the situation, with an analysis of every conceivable means afforded by nature for making determinations, impresses one with a feeling that here is a conspiracy of nature to prevent man from acquiring too much detailed information. A conspiracy of nature is a law of nature; we cannot pass it over as being of no importance. It is as if nature had erected a wall of impenetrability around the smallest particles and forced us to see them only partially, as if through cracks in the wall.

It appears, therefore, that we are asking a meaningless question when we ask just where an electron is when it has a certain definite momentum. No possible operation can be thought of by which an answer to this question can be secured without violating a law of nature. The conclusion is that the electron cannot have an exact velocity and an exact momentum simultaneously. There is an essential fuzziness

in the very foundations of nature herself. Time and space are a little peculiar in the microscopic region, most certainly.

Someone has said that "the infinite, whether the infinitely large, or the infinitely small, seems to carry disaster in its wake." I do not think the word disaster is happily chosen in this connection. It is true that the two infinities at either end of our linear layout have shattered the beautiful, crystal-clear mechanical system which described the universe during most of the nineteenth century—when the luminiferous ether was as definitely material as a piece of iron, and when a scientist could say that practically all pioneer research in physics was over and nothing remained except to measure things with increasing accuracy. This complacent attitude is fortunately gone forever, and the two infinities have had a great deal to do with its disappearance. The new problems presented, the paradoxes, the uncertainties, all combine to give us a picture of modern science once more struggling, once more growing. It seems better to change the quotation to read, "The infinite, whether the infinitely large or the infinitely small, seems to have carried renaissance in its wake."

In summing up the subject we may say that the small part of the universe, open to everyday experience, has given us a simple conception of nature, a simple body of laws, which seems unable to cope with problems either in the region of the super-nebulae or in the region of the extremely small particles.

In the latter field we have found that, properly speaking, descriptions of phenomena must be mainly mathematical. Such descriptions are quite adequate at present, and we feel that the main problems of explanation are well in hand. But we must be careful not to expect the same type of explanation that is used for objects of ordinary size, and we must remember that here there is a certain indefiniteness of be-

havior. We do not say that a small particle can *never* get over a high hill when it does not have enough energy to carry it to the top. We say that the probability of its getting over is small. It actually has a small probability of doing the job with an insufficient amount of energy!

In the region of the super-nebulae we are at present up against a paradox. We are at liberty to suppose that space is of a peculiarly curved character, or that it goes on to infinity; that the super-nebulae are flying away with enormous velocities, or that some unknown principle of nature is deceiving us. We may be affected by a feeling of futility because of this state of affairs, and even have a sympathetic feeling for St. Ambrose, who in 389 A.D. wrote: "To discuss the nature of the earth does not help us in our hope of the life to come. It is enough to know that Scripture states that He hung up the earth on nothing. Why argue whether He hung it up in air or on water? The majesty of God constrains it by the law of His will."

The spirit of modern science is not in agreement with St. Ambrose, and is not to be discouraged by apparent contradictions. This spirit demands continual arguing and speculating as to how the universe is hung up. Certainly we will always see as through a glass darkly, but just as certainly we will always keep on trying to polish the glass.

C. W. Heaps.

IV

SCIENCE IN THE HISTORY OF CIVILIZATION

IN THIS title the only word which does not give any serious difficulty to a scientist is "History." But he is really uneasy about the two others, "Science" and "Civilization." Fortunately, if one of the principles of what we shall call good thinking is the formation of good definitions, the scientist, or at least the mathematician, solves his problem by choosing them, logically speaking, arbitrarily. And if somebody dares to ask him, "Why this definition?" he has the right to answer—and generally uses this right, as he does in a freshman class when interrupted by a "Why?" after having begun, "Let *a* be positive"—"Because I desire it!"

It would be relatively easy to find a suitable definition for each of the two words separately. The difficulty arises from the fact that both occur in the same title. One cannot hope that the auditor will forget the given definition of "Civilization" when that of "Science" is being proposed. These two notions are so related that it would be most agreeable to give to Science a meaning so large, and to Civilization a sense so strict, that the lecture would be over after having merely suggested that, by definition, they constitute the same thing.

It is difficult to give a definition of our entities without reducing these words to others perhaps more difficult to define; we shall instead, contrary to all mathematical rules, appeal to the imagination and to concrete experience.

In a French dictionary which is generally considered a good one, we find: "Civilization—action of civilizing. Anti-

thesis—Barbarism"; and, "To civilize—to refine customs." Of course the dictionary makes here a fundamental mistake; or, if you prefer, we do not want this definition. This mistake could be compared in physics to a confusion between "potential" and "difference of potentials." Civilization corresponds to the second of these two notions and not the first. The antithesis of civilization is not barbarism. Civilization is what has been added to barbarism in order to obtain its antithesis. This has more than a philological significance. This interpretation shows better the dynamical nature which characterizes a true civilization. Not only is a stagnant state of things contrary to the notion we have of civilization, but even a uniform speed is not enough. A positive acceleration is necessary. If the members of a community live and think as they lived and thought fifty years ago without having added new ideas, or without having had new expressions of art or new ways of understanding social life, we shall not say that that community is civilized.

The word science is taken here in its typical English and French meanings: it means, in other words, "natural science," and not mere knowledge. The German word "Wissenschaft" has a larger and thus a less precise meaning. We shall therefore exclude history, social sciences, philology, and humanities in general, not because we do not consider them as an important part of human knowledge, but because the vague notion of "natural" we have in our mind excludes this kind of activities. Mathematics does constitute a natural science, not only because modern physics, chemistry, and other branches of typically *natural* sciences could not live without mathematical speculation, but because even the most abstract parts of mathematics as, for instance, topology, theory of groups, and others involve relationships between entities which, although created *a priori*, represent abstract forms

disengaged from Nature; at any rate, the relations between them symbolize relations between natural forms. If we recall that, after all, each science bases its conclusions, by necessity, only on a finite number of facts concerning the subject studied, we see that abstraction of an object is proper to a science. Mathematics thus must be considered, from this point of view, as the image of all sciences. We do not try to prove that mathematics is the Queen of Sciences—even though we think so! On the contrary, we try only to make you agree that mathematics is a full Citizen of the Kingdom of Science.

Science and applications of science constitute one—we should rather say two—of the components of our civilization. We shall give much more time to pure than to applied science. It is not that we have any contempt for the latter: we agree, of course, that the material achievements due to science constitute one of the terms of the difference, "Antithesis of Barbarism minus Barbarism." It happens that the purpose of this talk, as we understand it, is to compare creative, disinterested knowledge with two or three other activities of human intellect. On the other hand, two striking facts make it possible to assert that applied science, from the point of view of its influence on the intellect's desire to understand the world, or its place in the world, plays only a secondary rôle. First, true as it is that Science at the beginning followed its own applications, the technical applications which follow Science are relatively very recent. It would be difficult to find technical commodities resulting from scientific discoveries, and historically following these discoveries, realized more than two centuries ago. But science did exist in many different eras preceding this epoch. Second, since the era of great modern discoveries began, only a very small part of the new knowledge has been applied. By far the most pro-

found applications of Newton's ideas in mechanics have been made in astronomy, that is to say, in pure science itself, and not in technical achievements.

We shall not try to enumerate the different terms of what constitutes human progress; but let us, besides science, recall the most striking intellectual activities: religion, philosophy, arts. . . . In order to show the importance of science we could try to use a famous method used by mathematicians in order to prove the independence, with respect to one another, of different postulates which form an Axiomatic. One then tries to form axiomatics in which some postulates hold without the others being true.

It seems that Thibet is a good example of a country where only religion has been developed to a high degree; where a subtle theology is and has been for centuries the center of thought of a whole people, but where science is nonexistent; where art is, in comparison with religious achievements, poor; and where philosophy is entirely absorbed by theology.

There is also the prehistoric example of a community—nobody in our day is able to say how far this expression may be applied in those circumstances—a community where genuinely inspired art (painting) was probably the only manifestation of the intellect. We have in mind the Cro-Magnon man. His wall-paintings were, by their vivacity and inspiration, infinitely higher than the much later artistic expression of the Egyptians. Certainly no science troubled the brain of this ancient ancestor of European races; religion, on the other hand, was certainly reduced to magic rites and should not be envisaged as a product of intellectual activity.

But neither the ancient or modern Thibetans, nor the Cro-Magnon men could be considered as furnishing an example of something even similar to what we should like to call civilization, if we take as prototypes of civilization that of

ancient Greece, or that of the Renaissance, or that of our modern countries. In both cases, Thibetan and Cro-Magnon, science is totally absent. That is perhaps the point which makes the big difference. Of course a more rigorous evaluation of the importance of science as an element of civilization could be furnished if only it were possible to find and to study a community where science is the only intellectual activity. Perhaps an interesting example would be the comparison, from that specific point of view, between Czarist Russia and Russia of our day. The "homo sovieticus," as some writers call the members of the numerous states of the U.S.S.R., has, it seems, great admiration for sciences, though the expression of other intellectual activities is considerably reduced. But the Russian experiment seems to be too young to furnish a decisive proof of any proposition concerning the importance of science when other elements are missing.

In studying the total expansion of human intelligence, the French philosopher Auguste Comte thought that he had discovered the fundamental law that each of our principal conceptions, every branch of our knowledge, passes successively through three different theoretical states: theological, metaphysical, and scientific.

In Comte's mind the latest state, the scientific or positivistic state as he calls it, is the highest achievement of the human mind as far as the perception of the external world is concerned. We do not accept the philosophy of Comte since we believe that the three theoretical states mentioned correspond to three different and independent states of our mind; and we meet every day men who, in different moments of their lives, we should even say in different hours of each day, are under the influence of one of these states of mind. For these individuals none of the three states is subject to the others. But it is impossible not to accept Comte's law as a

historical principle. It seems obvious that at the beginning the human spirit tried to determine the intimate nature of things, the first or last reason of phenomena. This was the theological state. Then man, or at least the professional thinker, tried to replace the supernatural causes by abstract forces or abstract matters to which he gave different names; this is the metaphysical state. And only at the last stage did he try to formulate statements of physical laws based on experiments or did he try to idealize some of nature's laws. This is the scientific state.

Only in modern times have the rights and the fields of investigation of each of these three branches of human intelligence been delimited. It happened and it still happens that each one of these branches overlaps the neighbors' fields of activities, but essentially they are independent.

Hence until our recent epoch the history of human intelligence is a periodic function of time; every period, as far as the desire for the understanding of natural phenomena is concerned, is itself a succession of three different eras: theological, metaphysical, scientific.

Writers attribute the honor of creation of disinterested, rational sciences to the Greeks. As a matter of fact, the ancient physicists of the Ionian School, such as Thales of Miletus (640–598 B.C.), author of a famous cosmology where water played the fundamental rôle; Anaximander (610–597 B.C.), for whom the eternal substance was the basis of things; and Anaximenes (?–480 B.C.), for whom air was the great principle—all these physicists, in their metaphysical speculations, achieved the "laicization" of ancient oriental religions, principally those of Chaldea and Egypt.

But these same Masters of the Ionian School were perhaps the first men to lay down a bridge between metaphysics and pure science. Thales originated, starting from empirical rules,

the science of deductive geometry; he was able to predict an eclipse. Anaximander observed the revolution of the heavens with the pole star as center, and understood the existence of the other half of the heavenly sphere.

It seems that in Pythagoras (582-aft. 507 B.C.) and his School the three fundamental tendencies, described above, met. If he came back to mysticism—a mysticism based on the knowledge of numbers—he also experimented with sound and gave deductive proofs for geometrical theorems. It seems that he already knew the material of the first two books of Euclid. At any rate, he gave a real proof of the famous theorem, bearing his name, on right-angled triangles.

But certainly the most learned man of Greek Antiquity, the man who gave the greatest number of systematic theories in scientific fields already available, or introduced by himself, was Aristotle (384–322 B.C.).

His general ideas were of course too often wrong. For instance, contrary to Plato who had foreseen inertia, Aristotle asserted that an acting cause was necessary at every moment in order to keep a body moving. But he had ideas on planets, comets, and meteors. He was the first, in his *Meteorologics*, to treat chemical questions. He gave, for instance, ideas—of course false—on the origin of metals and minerals and on properties of composite bodies. In biology he used direct observation and inquiry on different animals. He used dissection and vivisection.

Aristotle's ideas in physics were particularly wrong, and the admiration and authority by which his name was surrounded during many centuries—and which were so merited by the genius of his daring spirit, if not by the actual discoveries—constituted one of the most formidable obstacles in the expansion of mankind's thought. The earth, though spherical, was the center of the universe. In a vacuum the

speed of fall would be the same for all bodies, but, argued Aristotle, this is obviously impossible. Thus follows the impossibility of a vacuum. He refused to believe in the atomistic theory already introduced and developed by Leucippus (5th cent. B.C.) and Democritus (460?–362? B.C.).

Feeling the necessity of experiments for the formulation of natural laws, Aristotle was still slave of the metaphysical desires of his time. He needed, if not "fundamental elements," at least "principal qualities"—hot and cold, wet and dry.

Aristotle's greatest discovery was probably that of formal logic, in forms which are acceptable, almost without variations, to the modern mind. He created thus the principle of rigorous proof. Certainly science would be impossible without the inductive method. But it would also be impossible without the deductive method. This method became rigorous because based on sure principles of Aristotelian logic. It is true that a modern scientist need not use rules of formal logic: he is logical (when he is!), as a result of his general education almost by atavism; but this education—this, let us say, artificial atavism—is largely due to the influence of Aristotle's logic on the Greeks who followed him directly.

The principal fault of the thinkers of the Middle Ages was that they started from false assumptions and made false theories by means of rigorous, formal logic. Often the false assumptions were introduced by the help of a little swindle —they were necessary for the proof of things conceived very much *a priori*.

The first true scientist of the Hellenic world, that is to say the man who was absolutely free from any metaphysical ambition, the man who did not try to find the leading element or the universal force, but who sought in experiments as well as in facts the explanation of other facts, was Archi-

medes (287?–212 B.C.). He personifies the third link of the first chain in history of human thought, the chain: theology, metaphysics, science.

Archimedes measured the circumference of a circle by methods which may be regarded as forerunners of the modern methods based on the notion of limits—he found the ratio of the circumference to the diameter to be a quantity of about $3\frac{1}{7}$. He found also the ratio of the volume of a cylinder to that of a sphere inscribed in it.

Archimedes was the creator of mechanics and hydrostatics. He was the first to introduce a clear idea of relative densities of bodies. Everybody knows the famous law of Archimedes concerning bodies immersed in a liquid. Archimedes announced the theoretical principle of the lever.

For the first time in human history scientific principles were applied conscientiously: let us recall hydraulic screws, burning mirrors, the pulley. . . . This is perhaps the right moment to recall that Archimedes used his genius to defend his city; for three years, thanks to his scientific advices, Syracuse could hold out against the powerful Romans.

The French thinker Ernest Renan used to speak about the Greek Miracle. We should not consider as a miracle, as Renan did, the fact that the Greeks were the first to think rationally and abstractedly: that is to say, in a way not immediately related to applications. But there was a miracle in the passage, *without any organized opposition*, from the theological to the metaphysical stage and then to the scientific. Such passages became very difficult and dangerous in later centuries. They were then accomplished in the midst of revolutions, not always bloody, it is true.

It seems that with the end of the civilization of the Ancient Greeks, and that of their Roman disciples (in science

they were almost mere imitators), there ends for a certain period the free evolution of human thought.

Creative minds always were few; they were, indeed, much fewer before the invention of printing and the organization of popular school systems, because only a few had any chance to think. But with the birth of a new religion and a new morality, the few great minds were all fascinated by the creation of a new philosophy. No room was left for things which were not directly related to religious thought.

When some centuries later the heirs of the first great theologians tried to have some ideas on nature, the Greek science had been forgotten and the human mind had lost its freedom. This freedom was lost in two different ways. The human mind was imprisoned by the limited means and fields of thought; it was also limited by a new fanaticism which made free thinking a very dangerous enterprise.

We shall make a leap over the Dark Ages, although this epoch saw the glory of Arabic science. We shall also omit the beginning of the Middle Ages with its rich expansion of Scholasticism.

It was during the most brilliant epoch of Scholastic Philosophy, personified by Thomas Aquinas (1225?–1274), that there appeared one of the purest precursors of the new scientific thought—Roger Bacon (1214?–1294). He was a great precursor, perhaps not so much by his real scientific achievements as by his scientific philosophy.

Bacon studied at Oxford under Lord Robert Grosseteste, Bishop of Lincoln, and Adam Marsh. Universities were organized at that time in almost all important countries of Europe. The University of Bologna, in Italy, was created about the year 1000. The Sorbonne was founded only in 1253, but a school of dialectics was organized in Paris as early as the beginning of the twelfth century and its con-

stitution was adopted by Oxford and Cambridge. Lord Robert, Chancellor of Oxford, was very learned; as Bacon puts it, "Lord Robert and Friar Adam Marsh were perfect in all knowledge." Bacon was thus educated in an atmosphere of knowledge, if not science.

But here is exactly Bacon's great contribution: he was not satisfied with "knowledge," that is to say with reading of Greek and Arabic authors. "The admirable Doctor," as Bacon used to be called, was the first man of the Christian Era who understood the importance of experiment. Certainty, he tried to prove, comes only after experience. Friar Bacon (he was a Franciscan) did not have an easy life. He had many ideas; he had also wealth which he was willing to spend for his personal research work, but his Order gave him a great amount of trouble. Fortunately for him, and for us, Pope Clement IV solved some of his difficulties in ordering him to write up his work.

We do not know whether we diminish or increase Bacon's fame in saying that it is probably not true, as some believe, that he invented gunpowder. But he did know the magnet and burning glasses; he described a telescope. He knew Arabic mathematics, which was mostly concerned with astrology. What is more important, he understood the significance of mathematics both as a tool for experimental research and as an influence on the qualities of the human mind. From that point of view he would have been a good educator even in our day.

Of course Bacon was not free of the mysticism of his time. But it can be said that Bacon constitutes a new Miracle—we do not speak in the name of his contemporaries! Unfortunately Bacon was too much of an isolated phenomenon in those times to have had any real influence on his immediate successors. We must wait for more than two centuries,

as a matter of fact until the Renaissance, in order to find another great and free mind. The name of the new colossus was Leonardo da Vinci.

Leonardo da Vinci (1452–1519) is perhaps better known to the world as painter, sculptor, and architect, but he was also a great physicist and biologist. No authority, neither that of Scholastic thinkers nor that of Aristotle, was strong enough to influence his powerfully original mind. He was perhaps also the first man of the Renaissance not to involve theology in the study of natural phenomena. We do not know whether Leonardo was acquainted with Bacon's work. But for him, too, experience was the only proof of reality. He, too, understood the spirit and importance of mathematics. He understood its abstract nature, but also its possibilities for application in the study of a set of experiments. It is significant that he was particularly interested in Archimedes' work. And from many points of view he was the Archimedes of his time.

A great number of principles which form the basis of rational mechanics were familiar to Leonardo da Vinci. It should be said that he was very much the engineer. He illustrates perfectly well the case where a man is a physicist because he is an engineer, and not an engineer because a physicist. He seems to have known the existence of acceleration during the fall of a body. He gave proofs of the law of the lever. He had very clear, if not very true, astronomical ideas. Leonardo da Vinci remarked that liquids in communicating vessels stand at the same level. He studied the laws of sound and remarked the analogies between the propagation of sound and that of light. He discovered important laws in hydrodynamics.

Leonardo da Vinci was perhaps the first Christian to dissect the human body, and this allowed him to make very

accurate anatomical drawings. He knew the functions of the heart. Some think that he knew the circulation of the blood perhaps as well as Harvey did later.

He did not believe in astrology and alchemy. Unfortunately Leonardo da Vinci never published his notes, which were discovered much later, but he was in touch with many great thinkers of his time and thus participated in the expansion of clear and new ideas.

The great astronomical revolution—we might have said the great revolution in human thinking—was brought about by Nicolas Copernicus (Nicolaus Koppernigk) (1473–1543), Polish astronomer and mathematician.

Ptolemy's geocentric theory satisfied almost everybody; it had the authority of Aristotle; it had also the blessings of the great scholastic philosopher Thomas Aquinas, who reigned over all educated minds of the Middle Ages. Theology and philosophy accepted this theory willingly, since it placed the center and the reason of creation—man—in the center of the world. It is true that the mathematical apparatus on which Ptolemy's conception depended was rather heavy, since a whole sky had to move round the Earth. And disciples of the Pythagorean School (who became numerous through the influence of Neo-Platonism, and especially of Saint Augustine's writings) were rather shocked by this lack of harmony. Let us not forget that everything had to be, in the minds of Pythagoreans, mathematically simple. Copernicus' theory had this advantage.

Above all a fixed sky with fixed stars. In the center of this sphere the sun. The farthest moving body is Saturn, which revolves round the sun in thirty years; then comes Jupiter, completing its revolution in twelve years; next Mars, in two years. The Earth comes afterward (revolving in one year, by definition!); then come Venus (nine months)

and Mercury (eighty days). Every planet spins on its axis. The trajectories were of course circles. Copernicus was satisfied with his own theory because of its harmony.

Many objections of even a scientific order were made to Copernicus' theory. If the earth revolves round its axis, why does not a body thrown upward fall to the west of its point of projection? Would not the earth, if Copernicus' theory were true, disintegrate? But Copernicus replied that a revolving sky with a fixed earth would do so even more.

Giordano Bruno (1548–1600) went even further: he dared to abandon even the idea that the stars were fixed, and believed, as we do nowadays, that they are scattered through infinite space. This was too much for his time. He was burned at the stake in 1600.

Until the sixteenth century there were only isolated periods in which epoch-making discoveries were conceived or during which science was advancing. In between two such intervals, not only science—physics, astronomy, mathematics—did not make any progress, but often known principles were forgotten. These progress-making time-intervals, in which sporadic expressions of human genius evolved, appeared more and more often. But if we try to go backwards from our times through streams of continuous progress, we should certainly be obliged to stop, at the end of the sixteenth century, or otherwise be obliged to make a great leap in order to meet Copernicus, almost a century earlier.

It seems, indeed, that the last great continuous interval—we have in mind continuity with respect to time—in which positive progress has been made, and which continues through our day, began with such men as Tycho Brahe, Kepler, Galileo. If we are looking for more than continuity in time; if we desire to establish a continuous path in our scientific way of thinking; if we want, still in retrospect, not to be

obliged to meet a kind of thinking almost inconceivable for scientific minds of the latest centuries, we should stop with the last of these three men: Galileo.

Here are the three astronomical laws of Kepler based on observations of Tycho Brahe: "(1) The trajectories of planets are ellipses with the sun in one focus, (2) the area swept inside such a trajectory by the straight line joining the center of the planet to the center of the sun is proportional to the time, (3) the squares of the periodic times which the different planets take to describe their trajectories are proportional to the cubes of their mean distances from the sun." These three laws constitute an important part of the sum total of human knowledge. And the astronomical achievements of many years which followed directly Kepler's epoch were based on his discoveries.

But the spirit which guided Kepler in his research was still of Pythagorean type—the nostalgia for the greatest geometrical harmony in the world. Fortunately, in its first approximation the truth about nature is harmonious; or it would be truer to say that we call harmony one of the properties of an idealized, simplified (too often over-simplified) world.

Galileo no longer cared for finding first or ultimate causes. As a matter of fact he did not care for causes, that is reasons, at all. He wanted only to know how things happen; he wanted merely to describe phenomena. This is also the modern point of view. When a physicist or an astronomer gives a mathematical theory of a set of happenings, he does not try to explain all of them; he merely explains some of them by some others. Mathematics serves only to make these transitions, or to describe the ways in which the phenomena which serve to explain the other phenomena occur. A scientific theory does not leave the field of phenomena or the field of their idealizations: that is to say, their mental simplification.

This principle is one of the most important axioms of our scientific civilization. It makes the difference between a professionally educated scientist and the layman who always has the kind of mysticism which we could call the pre-scientific "Why?" The nonscientific mind always wants to know too little but also too much. The great break-through, if you allow me this expression, in scientific thought was made when scientists were freed from the search for metaphysical reasons. They began to know how to limit themselves. Phenomena are explained only by other phenomena, which in turn serve to explain still other phenomena. Galileo was the first man, in the time-interval which continues through our day, to have this conception of science.

It is perhaps due mostly to the fact that he invented or, at least, materially realized the telescope. He had enough to do in his lifetime just in looking and in systematizing all he saw. And he did see a great many things. He could confirm, by observation, Copernicus' theory. New stars gave perhaps the first reality to the idea of infinity. He saw that the moon was covered with hills.

But the principal personal work of Galileo remains the foundation of dynamics. Causes are needed for acceleration and not for velocity. Of course only later Newton showed *how* causes of acceleration produce those accelerations. Galileo found that after running down one plane, a ball will run up another to the height of the starting point (friction being neglected). He discovered the law of isochronism of small oscillations of a pendulum and used his studies for the regulation of the clock.

Galileo was the first scientist as we understand the term today. He was also one of the last ones to suffer from religious fanaticism for his astronomical ideas—specifically for his proof of the improved theory of Copernicus. His book, pub-

lished in Florence in 1632, was denounced by the Inquisition, and at seventy he was obliged to recant, on his knees, these heretical theories of the universe. "E pur si muove!"—"And yet it moves"—were later his famous (and perhaps apocryphal!) words.

The expansion of physical science—in its larger meaning as the science of phenomena—and that of mathematics are so related that the birth of an idea in one of these disciplines follows that of an idea in the other one. Mathematics used by men of experimental knowledge inspired mathematicians and gave them the first elements to be extended and codified. But men with mathematical talent felt also that something completely new had to be invented in mathematics in order to provide a fresh impetus to the physical understanding of the world. The seventeenth century saw the beginning of this double collaboration—collaboration at a distance. It was also in the seventeenth century that the Greek Miracle —love and understanding of pure and disinterested mathematical thinking—found its reincarnation in its almost modern forms.

In connection with pre-Newtonian mathematics, three names have to be cited: Descartes, Fermat, and Pascal.

In his famous book called *Geometry*, Descartes laid down the foundations of analytic geometry. Not only had Descartes by his discovery introduced a new branch of mathematical science, but he had introduced a method of the utmost importance for the whole of mathematics. Analytic geometry made possible the finest study of geometrical figures by analysis, but it also made possible the intuitive study of analysis by means of geometry. From this double point of view it played later on a very important rôle in Newton's discoveries. Descartes insisted upon the fact that the equation of a curve allows the study of all its properties. We shall

not speak here about other technical mathematical discoveries of Descartes. Let us only remark that there is not a single exact science or a single technical domain in which Descartes' ideas are not applied.

Fermat was one of the greatest precursors of modern pure mathematics. It could be said that he founded the theory of numbers, one of the most beautiful and one of the least useful parts of mathematics from the point of view of technical applications. It would be wrong to take this assertion in a derogatory sense. It is pure mathematics, mathematics for mathematics' sake, which has made possible the progress of other parts of this science. It is necessary to push pure mathematics very far in order to find in this arsenal of pure knowledge a few truths useful for applications—few, that is, with respect to the whole body of mathematical knowledge. It is because mathematicians have had this pure curiosity that they invented analytic functions, absolute calculus, and matrices, which served afterwards for the foundation of modern theories of electricity, the theory of relativity, and others. But we feel almost sorry to give such reasons for the usefulness of pure mathematics. Mathematicians create pure mathematics as musicians write music, as poets write poems, as philosophers think about space and time. It is true that great physical applications of mathematical theories are made, almost despite the discoverers of these mathematical theories; but one of the noblest characteristics of our civilization is the existence of poets, musicians, and pure mathematicians.

Pascal was the discoverer of the calculus of probabilities. Unlike Fermat, Pascal would not need to apologize since probability is used in physics, biology, and even such practical fields of our life as statistics, economics, and insurance.

With the end of the seventeenth century begins a new era in

mankind's thinking. In 1687 Newton had published the first edition of his *Mathematical Principles of Natural Philosophy*. It could be said without exaggeration that this book constitutes the greatest scientific work realized by a single man. It may be said that Newton discovered the Universe, although he gave mostly its mechanical aspects, but at his time the mechanical aspect was the only aspect of the external world.

In establishing the law of gravitation and the equation of dynamics Newton gave the synthesis of the visible world, at any rate of the world visible in the seventeenth and eighteenth centuries. The parts of the Universe invisible even by a powerful telescope became potentially, if not actually, visible by mathematically necessary inferences from Newton's laws.

In separating the two notions, mass and weight, Newton created one of the most important abstractions of the human mind: matter—a concept as fundamental to mechanics as space and time.

The old mathematics was not a sufficient instrument for the new mechanical world. But Newton created the infinitesimal calculus. This great achievement of mathematical thinking was shared also by Leibnitz. Leibnitz' notations seemed, at least at that time, clearer, and were rapidly adopted by continental Europe; but, curiously enough, in modern mechanics it is often preferable to use Newton's original notations. Until very recently, and apart from a few exceptions, infinitesimal calculus and mathematics have been almost synonymous since Newton.

In one word, Newton created a mechanical world, the laws of which were expressed in forms of infinitesimal calculus. The abstraction of the operations used in establishing or in expressing these laws constitutes the new abstract world.

Newton was the creator of the two: the mechanical and abstract worlds.

Newton created modern optics in establishing the law of decomposition of white light by the prism as well as many other fundamental principles of physical optics.

Newton's work brought into being a new spirit. It seemed to his successors that potentially the world was understood. Only details remained to be established. It was sufficient, they thought, from now on to look, to look ably; but the principles were there. Determinism and mechanical Materialism were born. The greatest part of the difference between the thinking of man nowadays and in the seventeenth century is due directly or indirectly to Newton. We do not hesitate to speak about the pre-Newtonian and post-Newtonian man, or at least the pre-Newtonian and post-Newtonian thinker.

The eighteenth century was, as far as astronomy, mathematics, and physics are concerned, rich and original; but astronomy became mostly celestial mechanics, and mathematics the theory of differential equations related to mechanics. Such men as d'Alambert, Legendre, Lagrange, Laplace, and in a large measure Euler, all great mathematicians, lived in Newton's world and their discoveries had one purpose: to continue to refine and to complete (they thought it was possible) the mechanical explanation of the world.

Chemistry was much slower in progressing, and it was only with the discoveries of Lavoisier that this science became free from mysticism and all kinds of semi-philosophical ideas. Lavoisier decomposed water into hydrogen and oxygen, and thus, at the same time, discovered these two elements. By showing the properties of oxygen he was able to reject the old conception of phlogiston—that very special matter with negative weight. He proved that gases have

ordinary properties of matter. He proved that matter, even if it changes its forms, does not change in amount.

It is curious to notice how some theories survived from antiquity by passing through the stages mentioned at the beginning of this lecture. Such was the atomic conception which all through the Greek epoch and the Middle Ages attracted metaphysical minds. It lived without any experimental basis: only false causality and not less false finality seemed to justify its existence. Only at the beginning of the nineteenth century did Dalton (1766–1844) give a scientific and experimental foundation to this theory.

We enter into the nineteenth century—the Scientific Age. We have spoken only about certain branches of science, not because the other branches were not cultivated much earlier, but because the discoveries in those scientific disciplines do not seem to have profoundly affected the human mind until the nineteenth century. They constituted either sets of nebulous conceptions, or isolated facts which nobody seemed to recognize as fundamentals of the world to come. Electricity, magnetism, the relationship of both to the theory of light, biology, anthropology, the theory of heredity, modern mathematics, and the new physics were only born, one may say, in the nineteenth century.

But it seems to us that from the point of view of pure science, as great as the discoveries of the nineteenth century may have been, as revolutionary as they were, the Revolution of the Intellect, the almost physiological revolution, was accomplished before. One has the impression that during the Newtonian epoch, and even a century before, the human spirit struggled in cleaning up a mine-field, but once in a free field—free from obscurantism—this spirit could walk fast, although not without great difficulties.

It may be said that during the nineteenth and twentieth cen-

turies human ignorance has been in complete rout. Talent and genius found in their path only technical, professional difficulties; but since means of avoiding them are infinite, infinite also were new discoveries, new theories, and new sciences.

At the same time scientists came systematically and conscientiously in contact with everyday life. Results of discoveries of almost every science were used in improving human life. Engineers familiarized with the newest achievements of scientific research were able to change completely the conditions of men's lives. Since some of my colleagues have given or will give the specific results of these applications, I shall not presume to describe them. My colleagues will do that much better.

Let us only say that since the title of this lecture is "Science in the History of Civilization" and not "The History of Science," and since we have tried to follow the different steps of the influence of science on human intellect until the moment when this intellect became free and full of desires and immense possibilities, we think that we should stop here.

S. Mandelbrojt.

V

PLANNING OF CITIES

CITY PLANNING is the art and science of planning in a comprehensive way for the desirable future physical development of a city. Its object is to provide a basis for continued expansion of the city so that convenience, comfort, health, and beauty are not lost if the city becomes large.

A city plan if worthy of its name "plan" is, more or less, a blue print of what the city will be like in the future if built according to plan. Physically a city consists in homes, office buildings, stores, factories, public buildings, water works, parks, streets, railroad terminals, and many other man-made adjuncts to the living of its citizenry. Cities developed as a result of the natural desire of mankind to band together for mutual protection against enemies. They grew in size as opportunity for earning a living or enjoyment of life increased, and some grew into large cities if they presented opportunity for success in greater measure than was offered by other cities. A city plan is similar to but much larger than the plans for a house. In the house plan we have definite locations where the residents live, or the living rooms; where they rest, or the bedrooms; where their meals are prepared, or the kitchens, etc. What should we think of a house in which the meals were prepared in the bedrooms, or reading and study were performed where the automobile is supposed to be stored? Further, would a house satisfactory to the owner result, do you think, if the living room were built according

to the ideas and to meet the needs of John Doe, a stranger to the owner, the bedrooms according to the whims of Richard Roe, another stranger, and each other individual part of the house according to the ideas of still other strangers? It would be singular indeed if a very convenient house, to meet the needs of the owner, resulted. Similarly, lack of the building of a city to accord with a definitely preconceived plan cannot result in a city that will give the maximum comfort, convenience, economy, opportunity, and health to its citizenry. Lack of a plan is evidenced in practically all cities. Business and industry abound in residence sections. Residence sections have been placed where parks and parkways should be. Streets are narrow, discontinuous, full of jogs. Apartments, hotels, office buildings jut out to street lines and cut off front yards of residences. Residential sections decay due to age and expiration of restrictions and rooming houses and boarding houses replace them, gradually to be replaced, in turn, by slums. The first owners in the residential sections move into new residential developments that have the latest in comforts and conveniences and are restricted against encroachment of laundries, garages, filling stations, stores, etc., for a period of fifteen to fifty years. As time goes on and the new sections grow old and newer ones are developed, the cycle of bloom and decay is repeated. So cities expand their outer margins and leave many parts near their centers to decay. Travels over many portions of the United States and adjoining countries show this state of affairs to be widespread. They show also that intelligent planning has stopped the decay of land values in many cities, and can in many more.

Suppose an already existing city decides to have a plan made which is to be the guide for its future development and at the same time is a plan for the correction of errors in its

physical layout. The city planner collects all of the information obtainable concerning streets, public transportation, areas served by water, sewers and other utilities, territories from which pupils are drawn to each public school, on the distribution and density of population, how the city has grown in the past, what areas are growing most rapidly now, areas available for future growth. He represents these data collected on maps that show the facts as vividly as he can. He studies the street system and makes other maps showing the width, traffic capacity and locations of railroad grade crossings, dead ends and offsets in streets. He studies the trends of population growth and prepares maps to show these growths. He spends a great amount of time in the field studying the flow of vehicular traffic in the city, makes traffic counts of private and public conveyances as well as pedestrians. He prepares maps to show public conveyance routes and distances from these routes that residents are required to travel and the time they must spend on the public transportation vehicles in going to and from their work and homes. He collects information as to the use of railroad facilities of the city, the industries located along main line and spur trackage, the properties with rail frontage that are available for industrial use. He studies delay to traffic at grade crossings, possible separations of grade between street and railroad. He collects information concerning through freight handled daily on the freight lines of the railroads, the amount of freight hauled over the streets by motor trucks particularly where the routes leave the city. He collects information concerning the daily passenger train movement over the railroad lines and how many use each railroad station of the city. All of these data are represented graphically on charts and maps.

Much of this information is available in offices of Cham-

bers of Commerce, utility companies, street transportation and trucking companies, railroads, building permit offices, county clerk offices, but it remains for the city planner to assemble the information in one office, to represent the statistical data on graphs, charts, and maps, and to interpret the data as regards the trends of growth of the city and street needs to connect industries and shipping facilities. In many instances the information has not been collected previously, hence it must be obtained by traffic counts, field surveys, personal visits to the sources of information. In addition the type of building on every developed piece of property in the city and a certain zone beyond the existing city lines is ascertained by survey and use of records of the fire insurance companies, and then represented on maps. The race of occupants is observed where possible.

The time consumed on collection of these facts is great but well spent. As a rule there is the heartiest co-operation by those approached for data. A staff to do the work of collection can be trained more readily than experienced workers found available. The more care and time spent in collecting the data the better able the planner is to envision his problem and the better prepared to attempt a satisfactory solution of the many problems presented. Problems are varied and complex for they affect the life and work of every individual, group, business and industry of the community.

After the data have been collected probably it is obvious to the planner that the most pressing problem is that of communication within the city, that is, the study of major thoroughfares and the formulation of a major street plan. The industrial, business, and social life of the community in our modernized civilization depends to a large extent on free and convenient circulation of the various kinds of traffic on streets, thoroughfares, boulevards, and parkways as well as

on the proper provision for transit lines, railroad facilities, utilities, and waterways.

The street system of the city probably ranks first in importance in the problem of circulation since it is the skeleton of which most of the movement of men and goods of the city travels. All travel of the citizenry to places of work or recreation, whether in private or public vehicles or on foot takes place on the streets, boulevards, or parkways, and all truck haulage of goods to industrial establishments or railroad freight stations or the yards and docks at the waterways takes place on industrial streets. All travel to and from airports of the city occurs over the street system. The streets must provide direct and convenient routes over which people and goods may move quickly and easily from origin to destination.

An ideal street system would have radial thoroughfares, fanning out from the central business and industrial districts much like the way spokes radiate from the hub of a wheel. Short, straight routes from the center, where most people have been at their work, to the residential sections will permit these people to reach their homes more quickly and economically than any circuitous route. From an economic point of view the saving to the city in pavement costs and costs of curb and gutter, water and sewer line, telephone cables and gas mains is substantial. Saving in time and wear on the nervous system results and is worth a great deal. Short routes, with a minimum of delay, lower haulage costs for truck companies, result in greater haulage with a given amount of equipment and personnel.

Traffic not destined for the central business and industrial sections should be routed around them to avoid the delay at traffic lights in the business district and to keep from adding their volume to that of necessity in the business section. The

routes should be cross-town and around the business districts much like a series of rims on a wheel. It is the ideal of the city planner to provide these routes.

Major traffic streets should be of generous width, a minimum of one hundred feet. Many cities have impressive main thoroughfares which are able to carry with ease the large volumes of pedestrian and vehicular traffic which they inevitably draw if the city becomes a metropolis of its section. Some widths as great as two hundred feet have served nobly as main traffic arteries and speak well of the vision of the early builders of those cities.

About one-third of the area of the average city is given over to streets. However, it is not so much large area of streets but large area of the necessary major streets together with their correct spacing that determines whether the system will function well and permit of expansion. The major crosstown and circumferential routes should be at intervals approximating one mile and the radial streets may branch out at suitable intervals like the roots of a tree so that all sections of the city are within one half of a mile of a major radial, cross-town, or circumferential boulevard.

Between these major thoroughfares there will be minor streets of a width of some sixty feet which are designed for local access to property of the area between the thoroughfares. These local access streets may well be designed to discourage their use by through traffic and may be discontinuous, have jogs, and small capacity. Quiet and freedom from traffic danger will enhance the desirability of such areas for residential purposes, and their convenience for industrial uses.

Carrying capacity of streets is usually measured by the number of lanes of traffic that move on the paved portion of the street between its curbs. These lanes should be even in

number to discourage the cutting out and around other moving vehicles which results when an odd number of lanes are provided. Four, six, and eight lanes of traffic are provided on major thoroughfares of our more progressive cities. If there are more than six lanes the pavement should be divided so that the oppositely moving traffic may be definitely separated. Tests show that for these multi-lane arteries the capacity and safety is increased by a central dividing strip. The dividing strip may be narrow. If wider in the residential sections, it may be planted with trees and adds greatly to the attractiveness of the appearance of the city, as well as providing a medium for extracting carbon dioxide from the air and replacing it with oxygen. The dividing strip may well form a safety zone for pedestrians when crossing wide boulevards and caught by light changes.

Lanes for rapidly moving or truck traffic should be ten feet wide, for more moderately moving vehicles nine feet, and for vehicles parked parallel to the curb about seven feet. In very many American cities curb parking has become a habit, and where it is ingrained must be reckoned with. To park a line of cars on each side of the street at the curb and parallel to the curb requires fourteen feet. To provide one fast and one moderate line of moving traffic in each direction requires an additional thirty-eight feet. So a curb width of pavement equal to fifty-two feet is required for the four moving and two parked lane type street. Sidewalks fourteen feet wide on each side (and these are inadequate in width on business streets) take eighty feet of right of way, or street width, with no allowance for increasing the traffic capacity of the paved portion as the city grows and its traffic demands greater carrying capacity. Seventy-two feet between curbs is about the desirable maximum for one line of parked vehicles and three lines of moving vehicles on each side of the street, unless the

dividing strip mentioned previously is used. A seventy-two foot paved portion requires a one hundred foot street width if there is to be a fourteen foot sidewalk on each side.

Progressive city planners consider provision for parking of vehicles on major streets very poor practice, and only design street pavement widths to accommodate the parking because it is an established custom. In a number of American cities studies have been made of the cost of on-street and off-street parking. The studies have shown conclusively that it is cheaper for the municipality to purchase vacant blocks on property with deteriorated improvements than to furnish an equal storage space paved to street pavement standards for the parking. Longer time and more economical parking can thus be provided on off-street blocks, with greater business resulting for stores and more convenience to the public using the parking lots. It is to be understood that such parking is free to the users and includes parking attendants. For those interested, details may be found in a recent pamphlet entitled "The Parking Problem," a publication of the Eno Foundation for Highway Traffic Control under date of September 1942. The conclusions of the Foundation are based on studies made in a number of cities of quite varying size and well distributed over the country. The primary function of streets is to carry traffic and not to serve as storage garages. Many cities have recognized this fact and prohibit parking on the major traffic arteries.

In an existing city with already established street boundaries we ask what may be done to relieve the congestion on the major thoroughfares. There are several possibilities: (1) restrict or remove parking (which is only a temporary expedient), (2) provide alternate routes, (3) widen the existing routes. The first is easiest to accomplish, and is a police measure, but accomplishes results quickly. The second and

third take more time. To provide alternate routes often means cutting through improved property to connect two or more existing streets which have been practically dormant as thoroughfares because they were not connected, and the procedure of connection may be expensive. The third or street widening is complicated by the fact that private buildings usually abut the streets, or tree plantings have been made on the sidewalk parking between the walk way and the curb, and residents are loathe to have these trees removed.

Where the object is to widen the street, that is, to set the buildings back, there are complicated problems due to moving structures built up to the property line back a sufficient distance, or to removing a definite portion of the front of the buildings and constructing new fronts. Both moving the entire building and removing and rebuilding portions are costly. In addition, the governing body of the city has the power to establish building lines, in front of which no new construction on vacant property may be built and no re-construction may be done on existing buildings. It is understood that the municipality compensates the owners for any lands so taken for public use. The procedure of establishing set-back lines and thus accomplishing street widening over a period of years is quite generally followed. It has the disadvantage of requiring time and the further disadvantage that the improvement, being in the future, may not be started, or, if started, may be lost sight of as time passes and other pressing problems arise. As a general thing the improvements in the central business district consist in large and expensive buildings. They are built over all or nearly all of the land of a given block. It is impossible to move them. It would be very expensive to cut the front from them and build a new front one panel or from fifteen to twenty-five feet back. Such a procedure would bankrupt the average city. Too, the large and high office

buildings, hotels, etc., of the progressive city are relatively new and have lived only a small portion of their normal useful life so it will be a long time before the buildings will be replaced and set-back building lines become effective for any street widenings. Hence, planners usually cannot attempt drastic widenings or cutting of new routes in highly built up sections either business or industrial, nor in residential sections that have valuable improved properties. Rather, they must relieve congestion by using the existing traffic ways more efficiently and by re-routing of traffic around the districts mentioned. The ideal often cannot be accomplished, but the prudent man strikes a balance between the ideal and what would be too costly or impossible.

Jogs and dead ends on major routes may be eliminated gradually as the finances of the city permit. Grades with railroads may be separated gradually, but it would be unreasonable to expect the citizenry and railroad managements to build costly under- or over-passes where any but the major thoroughfares cross the railroad rights-of-way. So the major street plans include a schedule of grade separations and a schedule for bridge construction where major streets cross any streams of the city. In addition especial effort should be expended in providing easy and uncongested access to the railroad freight and passenger terminals and to public buildings and airports. Enough has been said probably to justify the statement that the major street plan is the most important part of a city plan, and should command the greatest amount of study prior to its formulation. It requires unceasing effort to see that it is not lost in time, once it has been adopted.

If a city has an officially adopted major street plan, the platting of streets in new subdivisions can be brought into conformity with the plan with mutual benefit to the sub-

divider and the community. In Texas, city plan commissions of incorporated cities of a stipulated size by law have the right to require conformity of all new subdivisions within the city and in a zone five miles beyond the city limits existing at the time of filing of the plat. It is unlawful for the county clerk to record a plat of a subdivision unless it bears the seal of approval of the plan commission of the city. Plan commissions have rules governing the subdivision of land which are available for the use of subdividers. Such subdivision provisions are common in other states and work no hardship on any person or persons except the shortsighted and greedy. Practically all faulty streets result from lack of approval of subdivision plats and are the result of lack of foresight of the needs of a rapidly growing community. Where approval is not required the desire for maximum amounts of saleable land or subdivision in a given general area by more than one owner may result in lack of matching of streets in one portion with those of another, or a projection of a future major thoroughfare may be blocked by improvements thrown in its path unwittingly by the subdivider. Many chances for removal of jogs are lost. The result is devious routes and often dangerous jogs and joinings of traffic and accidents when the muncipality expands beyond the subdivision and the traffic becomes heavy. These unwholesome ends may be obviated by control of subdivision platting and patient adherence to the street plan over a considerable period of years. As new additions are made to the platted portions a fine opportunity is afforded for projection of needed main thoroughfares. Subdividers usually are civic-minded and cooperate readily in providing such extensions.

Boulevards and parkways and parks are essential parts of the city plan and tie into the major street plan. If the municipality is fortunate enough to have wooded streams

through its residential sections it may develop the areas on each side of these streams by landscaping them as park land and constructing parkways on either side of the streams. Many cities have been indifferent to their good fortune or unaware of their good fortune, and have allowed the wooded streams to become garbage dumps and sections of squalor. They may be made into areas of extreme beauty and great value to the community. No traffic except light vehicles should be permitted on the parkways. Further, private development of property should not be permitted between the parkways nor directly along the streams, whether it is residential or commercial development. Cities usually and rightly exclude truck traffic from its parks and parkways.

Many cities fail to realize the value of large and well distributed parks until the cities have grown to such an extent that available and suitable tracts of sufficient size have become unavailable or too expensive to purchase. Fortunately, civic-minded citizens often come to the fore and donate tracts as park lands. No more beneficial gift could be made a city and no more enduring monument erected to perpetuate the memory of a loved one than the gift to a city of parkland needed by it. The amount of area required as parkland is not well defined, but it should be a generous amount. Distribution is more important than mere size. Neighborhood parks of small size should dot the city and are useful in commercial and industrial as well as residential sections. Squares or plazas in the central business districts are a welcome spot for rest and a brief moment of relaxation in the built-up centers in many of our large cities. They are usually well filled when weather conditions permit. The major parks should have connections from the major street plan, but the local neighborhood parks should be somewhat removed to promote safety of the children on their playgrounds.

In recent years airports have become increasingly important. It is a small city indeed that does not have an airport. They are usually just beyond the city limits. That is not far out in a small village or city and presents little difficulty to the air traveller to transfer from airport to destination. In the large cities airport location is not so simple. Suitable sites are often far from the business centers. They must be very large, as flat and yet as well-drained as possible, and conveniently located to major traffic arteries to the center of the city. In addition to location and adequate size, the surroundings must be such as to permit take-off and landing from various directions without an excessive angle of take-off. Cities in hilly or mountainous country are faced by a serious problem and topography often plays a vital rôle. Expanding airways have already led to the construction of not only one but several airports in the largest cities. The city planner must be alert to the future airport needs, and allow for their provision in the plan.

All of the topics mentioned and briefly discussed so far have been problems of circulation or closely related thereto. A further closely related problem, on account of the need for ready access, is the location of a Civic Center. Public buildings of the city should be grouped together for greatest convenience and economy and as so grouped they are known as a Civic Center. In the center are included: the city hall, municipal auditorium, central post office, court house, central public library and other public buildings, including, quite often, museums. The civic center should be near the central business district but not necessarily in it. If so located it will be conveniently situated for all residents of the city. It must be located on major traffic thoroughfares, and may well be adjacent to a downtown neighborhood park, or such a park may be included in the center. By grouping of

the public buildings more emphasis may be given to their architectural beauty. Since public buildings usually have more emphasis given to their attractive appearance than some other kinds of construction, the opportunity is afforded for harmonious architecture. Builders of other improvements, by example, may be induced to pay more attention to the appearance of adjacent structures and improve the tone of the neighborhood around the center.

The control of private property for the protection of the citizenry is known as zoning. After the major street plan, zoning is probably the next most important factor in city planning. Zoning in a word divides the city into three major types of districts, residential, business, industrial. If the city planner were planning for a new city which was to be built he could say, "Here we will locate the business district, beyond the business district and along any navigable water and along railroad rights-of-way we will locate our industrial sections, here we will locate our apartment and family residence districts, and there we will have our single family residence districts. These areas we will devote to parks, fire and police stations"—and so on for all of the various appurtenances that go to make a modern urban community, and plan so that the whole could be expanded to make a great city. Few planners have such an opportunity, one exception being Major L'Enfant who was retained by George Washington when the infant United States decided to build our nation's capitol. Those who have marvelled at its magnificent system of streets, boulevards, parks, and general layout can realize what may be accomplished if the planner has vision and the opportunity to begin before a city is actually built.

In most instances cities have grown to a considerable size before they have thought of planning as such. Certainly many have been in existence a long time before zoning was

heard of, for it began in New York City as lately as 1916. Zoning is an attempt to remold a city into an ideal pattern such as would be obtained if it were remade and to avoid the mistakes of the first making. Its basis is the welfare of the majority of the people of the city and accords with our democratic form of government, the well-being and will of the majority of the people of the United States.

The "predominating uses of property" map, previously mentioned, shows the predominant uses to which the people of a given section of the city devote their land. If the land is used mostly for business, that land should be zoned for business. If it is used predominantly for residences, it should be zoned for residences. Similarly for all of the use classifications. For each section of the city the predominant uses map shows what the land is mostly used for, in many instances 90 or 95 per cent of it being devoted to a specific use. A tentative zone map may readily be prepared setting aside each part of the city for the specific purpose it is being mainly used for at the time of the survey. Zoning then attempts by law to continue those uses, to safeguard the homes and investments of the great majority of the people in their use of their land.

It has been found by experience that people prize their homes above other interests. They want them protected as homes. That this is so is proven by the widespread use of contract restrictions of residence property for residence uses for a definite period of years. When the contract restrictions expire and various businesses and light industries begin to creep in, the land begins to decrease in value for residence purposes as described earlier. Zoning replaces the expired contract restrictions with new restrictions if the residents of the area want them, and the zoning restrictions do not expire at the end of a given period of years. They remain in effect

until changed, after due process of law, by the expressed will of a majority of owners of property in the affected area. When carefully drawn zone ordinances have been put in effect citizens do not want them voided.

The procedure to establish zoning is simple. The tentative use zones prepared by the city planner are taken to the people of the city and explained and discussed in detail. This taking to the people is accomplished by dividing the city into small, convenient sections, establishing a central meeting place, and inviting the people of a given section to meet at a certain, convenient time in the stipulated meeting place. At the meeting the proposed "zone uses" for the area are gone over in detail and all residents present are invited to offer criticisms and suggestions for changes. Such suggestions are studied, and if there are revisions another meeting is held. This procedure is continued until a substantial majority of the property owners and residents of each area are satisfied with the zone uses proposed.

A zone ordinance is then drawn and the ordinance and maps presented to the city council or other governing body of the municipality. It is the duty of the governing body to hold final public hearings on the proposed ordinance before finally enacting it.

It might be well to describe zones in greater detail. As previously stated there are three use classifications: residential, business, industrial. Residence uses are subdivided into single family and multi-family use districts. Multi-family districts may be either duplex or apartment districts. Single family districts primarily are home owner districts. Property in multi-family districts is primarily rent property. Single family residences are permitted in multi-family or rent property districts but multi-family residences are not permitted in single family sections. It is not to be inferred that owners of

property in single family districts may not rent their houses if they so choose. New stores or industries may not be established in any kind of residence district. Local business centers are convenient and desirable and are provided, but industries are not placed in residence sections. Property in business zones may be used for residences or business, but industries are excluded. There are two types of industrial sections, light and heavy, the distinction being based on size of machinery, or use, or size of plant. Property in industrial zones may be used for residences, business, or industries. Thus one may build a house in a residential, commercial, or industrial section if he chooses, but he will not have stores and factories in the neighborhood if he builds in a zoned residence district.

Zoning is not retroactive. Uses and structures existing lawfully in a zone at the time of passage of the zone ordinance may remain in that zone even though they do not conform to the use zone provisions. An industry in a business section or residence section or any established business in a residence section is not required to move. It simply remains as a nonconforming use. It may not expand. It may not be rebuilt if destroyed by fire or damaged severely. No person is prevented by zoning from a reasonable use of his property. Any person who feels himself aggrieved has the right to seek redress in the courts. Courts have upheld the provisions of zone ordinances in a great number of test cases.

When the term "zoning" is used most people think of "use zoning." In addition there is height and area zoning, which stipulates the areas required in front, side, and back yards, and permitted heights of buildings. By requiring side and back yards in residence districts each structure is assured its fair share of the light and air of the neighborhood. The requirement of front yards is similar to building lines in residence districts having private deed restrictions. Use, height

and area zoning gives the owner of land in unrestricted residential sections what deed restrictions give the owner of property in newer subdivisions. Few people in unzoned cities would spend their money for property in unrestricted subdivisions. Zoning protects the property of the unrestricted district. Many cities have experienced new construction and re-construction in older unrestricted districts after the adoption of zone ordinances. Confident new construction results. Owners of older properties feel warranted in maintaining them and the process of decay is halted.

It is well to add that much property is held for sale as business property in growing cities after deed restrictions have expired. Since only about 1.5 per cent of the street frontage of property in the entire city can be supported by business of the city, it is manifestly impossible for all areas of cities to become business or potential business property merely because the deed restrictions on the residence property have expired. The land is not needed for business, few residents will venture to construct new residences on the land, so there is nothing for the property to do but age and thus decay, unless zoning is resorted to when restrictions expire.

If cities, and utility companies serving the people of the cities, know rather definitely what the land in the urban territory will be used for, and the probable density of population in the residence sections, and know the extent of the business and industrial sections, then both city and utility companies know what facilities to provide and a marked economy in utility costs results in the city. The required size of water and sewer mains, of telephone and light cables and of gas mains, may be anticipated. The probable numbers of lanes of traffic to be provided on the major streets all may be anticipated much more accurately.

So zoning ties into city planning very definitely and plays

a stellar rôle. It is no wonder that some fifteen thousand cities in this country have zoning, and that there are only three cities in the United States having a population over two hundred thousand that do not have zoning. No major city, once zoned, has invalidated its zoning ordinance. It is inevitable that mistakes are made in zoning cities, but these mistakes are correctible and the ordinances prescribe the orderly fashion to be followed in correction of these errors.

Finally it may be said that city planning attempts no miracles, but is an effort intelligently to preserve the good points of the community and to improve the weaknesses, that it is a continuing process requiring constant vigilance and much hard and painstaking care, unselfish work, vision, and constant effort to build a more useful, convenient, and pleasant city in which to dwell so that posterity may approve the thought expressed in the words of John Ruskin:

"When we build, let us think that we build forever. Let it not be for the present delight or for the present use alone. Let it be such work that our descendants will thank us for, and let us think, as we lay stone on stone, that a time is to come when these stones will be held sacred because our hands have touched them and that men will say, as they look upon the labor and the wrought substance of them, *See!* This our fathers did for *us*."

L. B. Ryon.

VI

CHEMISTRY IN THE INDUSTRIES

CHEMICAL INDUSTRY, in the United States, grew directly in answer to needs violently made evident by World War I. Before the War, American-made dyes were not even listed in the official census reports. Our farmers had to buy German potash and Chilean nitrate. Our physicians looked to Europe for important drugs and optical glass. America-bound ships, heavy with goods and raw materials, testified to our dependency upon foreign countries. At that time our homes differed little from those of our grandfathers; we used the same textiles for our clothes and the same finishes on our horseless carriages. All steel rusted. The best rubber tires were worn out after about three thousand miles of highly uncertain road service. During the war there was the terrific driving power of necessity. There was the insistent urge to do bigger and better things, faster and faster. Ideas were translated into practice. Better methods were developed. New machines and products appeared.

After the War every branch of American industry seemed to possess a consciousness of the enormous power of science and the significance of its application to industry. Here was a challenge to improve upon the old methods and customs, a time to branch out into absolutely new territory. Here was the time to make use of potential ideas and abundant raw materials. And so there came to the chemical laboratories, textiles, steel, transportation, food and other industries.

"It is science, not governments nor wars of conquest, that

opens to us new horizons." These words, spoken by the late Andrew W. Mellon, will bear repeating in these troubled times. This American industrialist realized that "improvement in the standard of living can come about only by reason of new discoveries and inventions."

The new nation, which appeared on this continent following 1918, would have seemed a fantastic wonderland in 1914 had anyone then had the imagination to foresee it. The automobile came of age; aviation was established as an industry; and the wireless of war became radio. When, on December 7, 1941, we found ourselves again at war on a global scale, we were living on a plane that bore little resemblance to the pre-war period of a quarter century earlier. Our clothes, our food, our homes, and our industry were all different. Furniture and hosiery alike were being made from coal, water, and air; dresses from wood, farm fertilizers from the atmosphere, and camphor from pine stumps.

This is a war of many metals, for we live in the age of alloys. An American bomber, fourteen tons of fiber and metal, waddles to the head of the long runway, poises for a moment, there is a thunderous roar, and she takes off. Her aluminum skin is dark with war paint, a camouflaging coat of dull black, dirt brown, and forest green. This metal marvel is answering the terrific pull of 4,800 mechanical horses. And yet each of these horses weighs barely over a pound. This wonder is achieved by modern chemical and mechanical genius working with new lightweight metals and new high-strength alloys. Here are aluminum, magnesium, and beryllium along with tungsten, vanadium, and molybdenum. Here are plastics, fabrics, and alloys, each efficiently doing its important part. The metals and alloys are fibers of strength in a great industrial nation. In this war of many metals the lack of a single one may be a blow worse than the loss of a battle.

Two of the most useful of all the metals exist on the earth in fantastic abundance—aluminum in the clay underfoot and magnesium in sea water. But so complicated is the job of extraction that we have known these metals in quantity for only a generation. Today, in airplanes and bombs of war, these lightweights shake the world. Aluminum, about one-third as heavy as iron, and magnesium, less than one-fourth of iron's weight, are chiefly responsible for the wonderfully low ratio of weight to power in the airplane engines.

Aluminum owes its origin, in its pure form, to the persistence and genius of a young American named Charles Martin Hall who, in 1886, discovered that when aluminum, purified from bauxite, was dissolved in a molten bath of cryolite, aluminum could be obtained by the electrolysis of this fused mass. Strategically our chief concern was the supply of cryolite and the production capacity of alumina plants. Fortunately, for this program, President Wilson was farsighted in pushing construction of enormous water power projects along the Tennessee and Columbia rivers. The aluminum industry is now using artificial cryolite. Aluminum can be extracted from alunite and this is now being done by a newly developed process.

Some twenty years ago a German scientist discovered that if aluminum were mixed with about four per cent of copper, one-half of a per cent each of magnesium and manganese, and if the resulting alloy were heated, quenched, and then allowed to age for several days—this light and relatively soft, weak metal increased its strength fourfold. This alloy is "Duralumin." New alloys, typified by 25S and 24S, have been developed which combine easy forgeability with good strength. Many of the alloys are quite vulnerable to corrosion. Pure aluminum, on the other hand, is highly resistant to corrosion since it immediately acquires a virtually invis-

ible coating of oxide which generally protects it from further attack. To meet this problem there has been developed a method of producing "Alclad" sheet with the strong alloy wearing a thin skin of protective pure aluminum. Wings of planes are made of this protected metal.

Aluminum, in this war, finds itself being used as an avenging agent of destruction. Powdered aluminum, plus iron oxide, forms the dreaded thermite used in incendiary bombs. In some bombs, the thermite merely serves to ignite magnesium which burns with an intense heat and a vivid white light.

In 1918 less than 150 million pounds of aluminum were produced. Direct war needs of aluminum in 1942 totaled around one billion pounds and the demand in 1943 will rise to two billion pounds.

On the wall of General Somervell's office hangs this motto: "We do the impossible immediately; the miraculous takes a little longer." This is just about what is taking place today. Laboratories are actively engaged in overcoming the difficulties encountered in the various industries and in controlling the production of practically every essential war material.

The story of the production of magnesium is extremely interesting. Its extensive commercial production is a triumph in the field of chemistry. One hundred years ago a scientist could have accurately stated that in 1943, man would be flying in the air like a bird; and that much of the metal out of which his machine was built had come from sea water and clay. It would be interesting to know how such a statement would have been received. For the first time in the history of the world a structural metal is being obtained from the sea. The magnesium is precipitated from the sea water as the hydroxide; the hydroxide is neutralized with hydro-

chloric acid; the chloride is dried, and then fused and electrolyzed in cells where the metal rises to the top and is skimmed off. The lightness of magnesium is amazing. A magnesium alloy girder, which one man can handle with ease, will support the weight of a heavy automobile.

Magnesium has about 60 per cent of the weight of aluminum. It sold, in 1915, for $5.00 per pound and was, until a few years ago, a structural curiosity. Today, measured by volume, magnesium at 22 cents a pound is cheaper than aluminum selling at 15 cents a pound. On the average, about a half ton of it is going into every fighting plane. After the war, the nation's capacity for producing this lightest of all structural metals will be more than double the aluminum output in 1939. Published data gave the capacity of the old plant of the Dow Chemical Company at Freeport as 125,000 pounds per day, using a flood of 25,000 gallons per minute of sea water. The plant has been enlarged until the original production amounts to only a fraction of the present output. Just try to visualize two hundred tons per day of magnesium ingots obtained from sea water in which the concentration of the magnesium amounts to only around 1100 parts per million. A computation of interest is that a cubic mile of seawater carries about 10 billion pounds of magnesium—enough to run our 1943 war effort and similar ones for ten years. There, in the sea, is an inexhaustible supply of industrial material.

Magnesium is seldom used alone. Add a little aluminum and it will gain sixfold in hardness and strength. Such a commercial alloy is the exceptionally strong Dowmetal which carries about 8 per cent aluminum with a little zinc and manganese. It will be of interest to know that the war plan calls for one billion pounds of magnesium in 1943.

But iron, composing about 5 per cent of the earth's crust,

is the most useful metal. More material has been taken out of the Mesabi Iron Range than was moved in the digging of the Panama Canal. And yet there is sufficient ore to last for hundreds of years. In the case of iron, the first industrial development came with the discovery that ordinary iron could be turned into strong versatile steel through the use of carbon. Even the ancient sword-makers, who pounded out the famed blades of Damascus, knew the magical power of carbon and the correlated methods of heat treatment. Nitrogen compounds, taken from interesting sources, were used in the quenching bath. Today tank armor is "nitrated" in hot ammonia gas, and the surface is thus "case-hardened."

Steel is challenging the light metals. Low alloy steels and new modifications of the higher alloy steels, fresh from the laboratory, are bidding for expanding uses. These new alloys are three times the weight of aluminum and almost five times the weight of magnesium, but their tensile strength approximates 190,000 pounds per square inch. This advantage permits weight to be shed by reducing bulk and eliminating needless supports. The alloys are less subject to corrosion than plain steel. Putting wings on freight cars is just about what American industry is now doing—building air freighters of tremendous proportions to carry carloads of supplies to our nation's forces in the far corners of the world. Many months ago, plans were put into execution for the construction of giant all-stainless steel cargo planes—planes that would have the strength and stamina to withstand the vibrations and stresses encountered under severe flying conditions.

Precise knowledge of exactly what happens in steel formation has made possible a great variety of alloy steels with definite characteristics. Chromium, the element which imparts precious color to rubies, imparts something more precious to steel. It gives steel incredible hardness and re-

sistance to heat and corrosion. It makes steel strong, yet ductile and shock-resistant. Chromium is the key that has opened, and is still opening, great new fields of application for steel. Without chromium the whole wonderful series of stainless steels would not have been possible. From tarnish-free tableware to corrosion-resistant chemical equipment; from strong, light-weight truck bodies to streamlined trains and airplanes; from heat-defiant boiler tubes to high-temperature steam turbines, chromium has made possible a steel with desired properties of the noble metals. But the stainless steels are only one great contribution of chromium. This element has also helped to provide long-wearing engine valves, strong, tough gears, tools, ball-bearings, shafts, springs, and hundreds of other improved articles. When engineers, about fifty years ago, produced chrome-steel projectiles that easily pierced the best armor plate of the day, all the warships became obsolete overnight. The answer was, of course, armor plate of chrome-nickel steel. Some years ago we were practically dependent upon outside sources for chromium. At that time our relatively low-grade ores made it impossible for domestic producers to compete with foreign suppliers who had the advantage of richer deposits. Now concentration methods have been devised which make this ore available.

What nickel has to contribute to the industrial field is not only corrosion resistance but also physical and mechanical properties which give the metal, particularly in alloy form, definite structural importance. To a considerable extent the participation of nickel is through nichrome alloys and monel-metal, the 32-68 nickel-copper alloy which now is produced with the strength of steel.

Tungsten is another strategic metal. Since sheelite glows with a fluorescent light in the rays of an ultraviolet lamp,

prospectors hunt the tungsten at night. The richest strike yet made is in central Idaho where men, hunting for antimony, stumbled upon a very high-grade deposit of tungsten ore. To a modern industrial country, at war, there would be few catastrophes to compare with a real shortage of tungsten. It gives strength to steels and armor-piercing projectiles. It has that sterling property of getting hot without losing its temper. Tungsten carbide tools cut at speeds so great that the edge is blue-hot from the fierceness of the friction. Oil-field drilling bits are "faced" with tungsten carbide. They will drill through solid quartz.

Ranking high as a toughener of steels is molybdenum, "Moly" for short. Alloyed with steels it takes out the creep, which is the tendency of metal to stretch under strain. Of major importance is the discovery that molybdenum can be substituted for much of the tungsten in making high-speed steels. In molybdenum supplies we are indeed fortunate for this country produces more than 90 per cent of the world's requirements.

In brasses, bronzes, and innumerable alloys, copper is vitally needed for cartridge cases, bullet jackets, propellers of ships, electrical equipment, etc. Modern concentration methods have made it practicable to extract the small percentage of copper even from old waste dumps. The water, flowing from the mines, is made to yield copper—6 million pounds per year—through the utilization of your old iron cans and other iron scrap over which the water is caused to flow. The copper is replaced by the iron, forms heavy sludges, and is recovered. Less than 2 per cent of beryllium, if alloyed with copper, will make that metal so hard that it will cut steel. Used in springs and diaphragms of delicate instruments, these alloys stick to their job under fiercely corrosive conditions.

Certain finite properties in steels are gained by the addition of the alloying elements. The effects of some have been discussed. Vanadium imparts toughness to steel; selenium gives free-cutting characteristics; nitrogen leads to grain refinement; thorium, titanium and columbian inhibit carbon precipitation; sulphur gives better machining properties and zirconium is added to hold the sulphur.

Mercury, as fulminate in shells, touches off the thunder of high explosives and the fury of incendiaries. It is used in the anti-fouling paints to keep barnacles off of ships; in fluorescent lighting; and for many other purposes. One General Electric mercury boiler, supplying mercury vapor to drive a 20,000 kilowatt generator, carries 270,000 pounds of mercury in its system. Sodium metal is added to the mercury to give better heat transfer, and zirconium is added to retard the solution of the boiler iron by the mercury. It should be interesting to note that the mercury-vapor condensers are really steam boilers, operating on a lower temperature plane.

Already concentration of low-grade ores has been mentioned. One ingenious process, flotation, has added many so-called "worthless deposits" to our natural supplies. Flotation is a process whereby the grains of one or more minerals, or chemical compounds, in a pulp or slurry, are selectively caused to rise to the surface by the action of bubbles of air. The grains are caught in a froth, formed upon the surface of the liquid, and are removed with the froth, while the grains which do not rise remain in the slurry and are drawn off at the bottom. Chemical collectors, frothers, depressers, and deflocculating agents are added to increase the efficiency of the separation.

In the Minnesota district a mixture of oleic acid with pine oil, modified by sodium silicate with sodium carbonate as a protector, suffices to give excellent concentration of man-

ganese ore. The flotation of phosphates is, by far, the greatest application of the flotation process to non-metallics. In Florida 11,000 tons per day are recovered from deposits at one time considered worthless. From the standpoint of chemical engineering a novel adaptation of flotation has come in the separation of potassium chloride from sodium chloride. The crystals are separated from each other in a saturated brine made up from the crude mixed salts as they occur in natural saline lakes.

In the field of sanitary engineering appears the problem of supplying safe and relatively soft water which will be used in the municipality for home consumption as well as for the industry. Good water for drinking purposes has doubtless been appreciated by the human race from time immemorial. Among primitive peoples the question of water supply was never of passing importance, except in arid regions. Recent archeological explorations in India have shown that five thousand years ago these people were living in well-built cities provided with well-constructed water conduits covered with marble slabs. The ancient water tanks in Arabia may have been built as early as 600 B.C. The infiltration galleries for collecting ground water at Athens were probably constructed two thousand years ago. Probably no more elaborate system of public water supply was provided for any ancient city than that of Rome. Three groups of springs in the volcanic plain on the left bank of the Tiber supplied the water to be conveyed by aqueducts to the city.

The requirements for municipal water supplies are that there should be no disease organisms present, that the water should be clear, colorless, and odorless; that it should be reasonably soft and non-corrosive; that it should be free from objectionable gases and minerals; and that it should be plentiful and cheap.

A river is often the source of supply of raw water. At the water-treatment plant coagulents are added and the water passed into large settling basins. The water is then efficiently aerated, oftentimes by sprays and waterfalls of architectural splendor, in order to eliminate any hydrogen sulphide present or to oxidize the iron and manganese. Filtration removes most of the suspended materials present and, at the same time, a large per cent of the bacteria. If odors and tastes persist, activated carbon is added before the filters. If the water is too hard it may be necessary to soften it to some desired degree through the use of lime-soda chemical treatment. The prevention of excessive scale formation from hard or unstabilized water has been one of the most stubborn problems for the water plant operator to solve. By recarbonating the water following the softeners, he could prevent after-precipitation more or less completely; but if he were successful in stopping all precipitation he would very likely be plagued by red water. "Threshold Treatment" offers a new method of control. This consists of adding a very small quantity of hexametaphosphate. When two parts per million, or even less in some cases, are added to the water, all precipitation of calcium carbonate is prevented. The economic advantage of the threshold treatment is the relatively high alkalinity which may be maintained, thus inhibiting corrosion.

Although softening and filtering remove a very large per cent of bacteria present in the water, yet the water is not safe. The remaining bacteria must be killed. The practical development of chemical disinfection has occurred during the last twenty years and by far the most commonly used disinfectant is chlorine. The chlorine attacks the bacteria, causing their elimination. There are indications that there are direct chemical combinations with some forms of bacteria. After such a chemical reaction there would be a com-

pound which might be called, "Bacterium Chloride"—BCl—a chemical compound and no longer a bacterium. Some two to five pounds of chlorine are added per million gallons. An excess is added to maintain a residual chlorine content of around 0.2 part per million in order to maintain sterile conditions. By adding ammonia along with the chlorine the destruction of bacteria may be made just as certain but much less rapid. This means a greater penetration down the mains and protection even to the very end of the lines. This "chloramine" treatment was started in Houston in 1933.

We are sending our soldiers, sailors, marines, and aviators away from the safest drinking water in the world. Swamp water of the South Pacific islands, polluted streams of Europe, drainage ditches of Northern Africa—all may be endured by the natives, but they are not good enough for our men. Even during peace times travelers tell us that wines and boiled beverages are the only safe liquids that can be used to satisfy thirst when in some of these countries. There may be some difference of opinion as to whether this may or may not have been serious, but enormous amounts of good water must be furnished to our fighting men. The Army and Navy health engineers have redoubled their efforts to safeguard every drop of water which our expeditionary forces drink. As the armed forces can transport only an infinitesimal amount of the water they use, modern purification units must be on, or near, the battle lines. Chemicals are, as usual, in there battling not only to make water safe from harmful bacteria, but clear, colorless, tasteless, and odorless. Chlorine and aluminum sulphate are two of the principal chemicals employed in these light portable water-treating units.

An Army Quartermaster Corps sends out mobile laundries with our troops to all parts of the world. Each of these laundries has to keep some 15,000 soldiers' clothes clean, no

matter what part of the world it is in. And at some of the places they say that the water "is so hard that it bounces." New detergents, containing soaps which do not give insoluble precipitates with hard water, have been developed. These soaps produce a perfect lather no matter how hard the water may happen to be.

Even though the excess hardness has been removed by the municipal water-treating plant, the industrial plants, especially those in which scale may be formed due to concentration or heating, must have even softer water. For the past fifteen years the trend has been to higher steam pressures in commercial boilers. This is advisable in order to improve the plant cycle efficiency. The high pressures of former years, like 500 pounds per square inch, are giving way to pressures of 1200 or more. At high rates of heat absorption, even a scale 0.01 inch thick may cause failure due to burned-out tubes. When solutions which contain salts whose solubilities increase with an increase in temperature are concentrated beyond their saturation value, these substances deposit as sludge. If their solubilities decrease they form scale. The formation of scale occurs *in situ*, that is to say, these constituents deposit directly upon the heat-transfer surface as scale. Sludges remain in suspension and are constantly removed from the boilers by the blow-down.

At low pressures sodium carbonate may economically be added to the feed water in order to cause precipitation as sludge, of calcium carbonate, not of the chief scale-former, which is calcium sulphate. At higher pressures with associated higher temperatures, phosphates are added. They do not decompose and yet, as in the case of the carbonates, they form precipitates whose solubilities increase with temperature; and consequently they form sludge—not scale.

For the successful operation of a boiler it is just as im-

portant to protect the boiler metal from corrosion as it is to prevent the formation of scale. The mechanical engineer looks at the boiler as a perfectly solid, stable piece of equipment. The chemist considers it as something subject to continuous slow reaction between the water and the steel, the rate of the reaction being fundamentally affected by the composition of the water and materially increased by higher temperatures. The entire region of chemical protection lies on the alkaline side—in a comparatively narrow range at high temperatures. Therefore one of the essentials for protecting the boiler metal from corrosion is that the water must be maintained in this specific alkalinity range. Since the corrosion rate is proportional to the oxygen content, the oxygen must be completely removed. This can be done very effectively by mechanical deaeration followed by chemical treatment. Sodium sulphite is maintained in the boiler and serves as the vigilant policeman. It is kept ever-present in order to eliminate at once any oxygen which might slip into the system. The deterioration of boiler metal, characterized by cracking of plates and rivets along submerged riveted seams, is referred to as caustic embrittlement. This type of failure is caused by simultaneous chemical action and stress. The disastrous effect of soluble silica in alkaline solution has been conclusively demonstrated and seems to be the principal cause of such failure. Its nearly complete removal can be attained through the use of hydrous magnesium oxides. Many of the operators of boilers in high-pressure ranges regard one-piece forged or welded drums as an adequate guarantee against serious trouble caused by silica.

Many industries use distilled water as make-up for their boilers. Due to condenser leakage and the addition of chemicals for corrosion control, treatment is still necessary. Quite generally lime-soda softened water is most economical but

some waters lend themselves to softening more cheaply through the use of exchange zeolites.

By the action of hard waters on certain complex silicates, both natural and synthetic, an exchange of the calcium and magnesium for the sodium of the zeolite may be brought about. These zeolites, when exhausted, are revivified by passing a strong solution of common salt through them. After thorough washing, the cycle may be repeated. The zeolites were used originally as sodium zeolites, and since calcium and magnesium are basic, the term "base exchange material" was often applied. Research has now given us a carbonaceous zeolite, "Zeo-Karb," which is free of dangerous silica. When regenerated with sodium chloride it functions as the early zeolites. When regenerated with dilute acid, not only the calcium and magnesium, but also the sodium, may be removed. Used in this manner we have a "Zeo-Karb H" unit.

With the advent of this zeolite it became possible to replace all metallic ions with hydrogen ions, leaving only the corresponding acids in solution. Now it is obvious that if the free acids could be absorbed by some insoluble substance which could be regenerated and operated indefinitely in repeated cycles it would be possible to remove the soluble salts entirely. Such exchangers have now been developed which, in some respects, even excel the earlier cation exchangers. Typical of these exchangers is the aliphatic-amine resin, called "De-acidite." Now we have a two-step commercial unit: the first removes all the metallic components and the second extracts the acids. Deaeration removes practically all of the carbon dioxide and the effluent from the process analyzes as H_2O—nearly as free from soluble materials as if it had been distilled.

Other applications of these exchangers might be the com-

mercial removal of magnesium from sea water, the demineralizing of sugar solutions at various stages in refining, the removal of salts from many impure solutions or as a unit accessory in life-rafts for the purpose of making drinkable water from sea water.

After the water is used in the city it is sent into the sewers which convey it to the sewage disposal plant. At many such plants the sewage is aerated in large open basins so that aerobic bacteria can thoroughly digest and decompose the organic matter. Coagulents are added after mechanical concentration of the sludges; the solids are filtered out, dried, and made into balanced fertilizers. The clear, sterile, effluent water may then be returned to the river from whence it came.

Today the petroleum industry has changed from almost a non-technical industry to a very technical one. There must be a highly trained exploration and production staff, a carefully trained research and development department, a technically trained control laboratory, an engineering and refining staff, and finally, a co-ordination and sales department. Petroleum is a chemist's and chemical engineer's business. Chemical control follows the oil from its original formation to its final usage.

Soil and gas analyses indicate presence of petroleum formations. Chemical control of drilling muds insures most efficient drilling conditions. Hydrochloric acid, inhibited with amines to protect the drilling equipment from attack, is used to open up limestone formations. Emulsions must be broken to lower water content to the point where the oil can be pumped into the oil lines. Casinghead gasoline recovery plants must be designed, installed, and operated under absolute control. And finally, in the refinery, ultimate control is chemical in nature whether it be in the straight run or cracking unit, in

the acid-treating or dewaxing plant, or in the treatment of the boiler or cooling water.

Some years ago it was thought that the ultimate in motor fuel would be reached by the creation of a gasoline equivalent in power and anti-knock qualities to those of pure iso-octane. So superior was iso-octane in these respects that it was arbitrarily given the octane rating of 100, which became the standard in evaluating all gasolines. Extraordinary strides have been made in the fabrication of airplane engines, propellers, and bodies. The advances in design and construction of the engines have been made possible, to a large degree, by the oil industry in producing the 100-, and higher, octane gasoline and all the necessary lubricants. Increased manifold pressure increases explosion pressure and requires a higher octane fuel in order to avoid detonation. The use of superchargers, with high-octane fuel, increases the speed, cruising ranges, and ceilings of the planes. The use of 100-octane aviation fuel will give our aircraft a definite advantage over aircraft of our enemies and may, in effect, be one of the deciding factors of the war. The octane ratings of aviation gasoline which has been collected from captured and shot-down German planes average around 87. It has been reported that the German invasion of England in 1940 was stopped by the R.A.F. because the English fighting planes were powered with 100-octane fuel.

Tetraethyllead, the product of Midgley's researches, broke down one of the barriers that was blocking the road to automotive progress—the barrier of "knock." Added to gasoline it increased the power and performance of many million automobiles. Although tetraethyllead has played an extremely important part in increasing the efficiency of gasoline engines, it will probably lose its importance due to the high-octane gasolines which chemical technology is rapidly providing.

Military airplanes in 1928 used gasoline of about 60 octane rating. In 1931 the standard Army aviation gasoline was 87-octane and airplane engines were developed to utilize this quality fuel which gave a 33 per cent increase in power per unit weight compared to 60-octane gasoline. Engines, designed for using 100-octane gasoline, yield 15 to 30 per cent greater output while take-off distance is reduced 20 per cent and climbing speed increases 40 per cent. Leadership in aviation octane gasoline rests in the United States. Mr. Bruce K. Brown, Assistant Deputy Coordinator for War, said in September: "It has become quite evident that the needs of the United Nations for 100-octane gasoline will eventually exceed the productive capacity of all aviation gasoline plants now built, building, or authorized." Such reasoning undoubtedly led to the curtailment of the synthetic rubber program.

Cracking, in the petroleum industry, may be defined as the breaking down of the hydrocarbon molecules into smaller ones with attendant polymerization and other side reactions. When cracking by heat was first recognized, its only commercial significance was as a possibility for producing more kerosene from crude oil. The process was stimulated by the advent of the automobile and the airplane. Cracking, in the beginning, was a thermal reaction taking place in liquid phase. The stills became a combination of pipe still, pressure reaction chamber, and fractionating tower. The Burton, Cross, Dubbs, Holmes-Manley, tube and tank, and other processes were modifications differing in engineering design. The science of cracking is distinctly an American development and its commercial application an American achievement.

Later research showed that high temperature favored the production of better octane fuels. Cracking was developed

to take place at high temperature in the vapor phase. The vapor phase processes, like the deFlorez and the Gyro, produced a higher octane product but gave a mixture rich in unsaturated hydrocarbons and thus suffered in stability. The problem confronting the chemist a decade ago was to convert the straight-chain hydrocarbons, which have low octane numbers, to the so-called side-chain hydrocarbons which have much higher octane numbers. Most of the development in recent years has been along the line of catalytic cracking. By means of suitable catalysts the desired reactions have been made to take place at lower temperature and the effect of the undesirable high temperature reactions has been minimized.

Gasoline may be made from petroleum gases by polymerizing, which is the combining of two or more simple hydrocarbon molecules into a more complex one. Thus, for example, when two molecules of the unsaturated hydrocarbon butylene combine they form dibutylene which is still an olefin, but is now a liquid instead of a gas. The catalyst, phosphoric acid, polymerizes olefins in cracked gases to motor fuel of high octane rating. This same catalyst is used for the production of 100-octane aviation gasoline by selectively polymerizing butylene to iso-octene and hydrogenating the latter to iso-octane. This simple polymerization process made a revolutionary change in the oil industry. This process is conserving crude oil at the rate of many million barrels per year, and in addition is producing a motor fuel superior to that derived directly from crude oil. The interesting point is that these gasolines are being obtained from refinery gases which were once burned only as fuel.

Another process, called "Alkylation," refers to the uniting of an olefin and an iso-paraffin in the presence of sulphuric or hydrofluoric acid catalysts. What makes these processes so

important is that, in every case, these molecules unite in side-chain arrangements and the resulting synthetic gasoline has an octane number approaching 100. Thus a high-quality gasoline is developed and a use found for the 300 billion cubic feet of practically waste gases formed yearly by the cracking process.

Isomerization is the conversion of straight-chain to branched-chain molecules. The need for isobutane, in alkylation, has emphasized this isomerization of normal butane. The new Isomate process isomerizes pentane and hexane to form a product to be used directly in gasoline. Hydrochloric acid and aluminum chloride are used as catalysts.

In the hydroforming unit the catalyst converts low octane naphtha into high octane aromatic gasoline. This process involves the circulation of hydrogen in the admixture passing over the granular catalyst. A yield of as high as 20 per cent toluene is obtainable. On the basis of 7500 barrels of naphtha feed per day, a toluene production of five million gallons per year, would be possible. The enormous production of toluene, when made into TNT, Tri-nitro-toluene, will provide very effective April showers for Germany . . . showers of four- and eight-ton "Block Busters."

Catalytic cracking processes may be broadly classified according to the physical state of both the catalyst and the reacting hydrocarbons in the reaction zone. These hydrocarbons may be reacted in either the liquid or vapor phase, whereas the material acting as a catalyst may be solid, liquid, or vapor. In the present commercially important processes for catalytic cracking, the Houdry, Fluid Flow, and T.C.C. (Thermofor Catalytic Cracking), the hydrocarbons are substantially vaporized and cracked in the presence of solid catalysts.

Many types of catalysts have been developed for use in

these three processes, but at the present time contact—or adsorptive—type materials, comprising chiefly silica-alumina composition, made by synthesis or by the chemical treating of natural clays, are used almost exclusively for this purpose. Cracking processes, employing the solid-type catalysts, may be divided further into two basic types according to the method of applying the catalyst. One system appears in which the catalyst mass remains static in the reaction zone and the vapors pass over the fixed catalyst bed. The Houdry units exemplify this type. The other is one in which the catalyst moves continuously through the reaction zone. The Fluid Flow and TCC belong to this class. The differences between the TCC, Houdry, and Fluid Flow processes lie chiefly in the physical methods employed in handling the catalyst, in its size, in contacting the oil, and in regenerating the catalyst.

The first Houdry units were placed in operation in 1936. In this system a number of catalyst units, alternately operated as a catalyst chamber and then being regenerated, serves to maintain a continuous flow through the complete unit. In this system the catalyst remains fixed in its case, serves as a catalyst, is regenerated, and used again.

The TCC process, licensed by Houdry, derives its name from the Thermofor, spiral-finned, type of clay-burning kiln which is employed as the catalyst regenerating unit. In the TCC the catalyst is in the form of granular pellets of from 4 to 60 mesh size. In this form the catalyst mass flows freely through the equipment. There are separate reactor and regenerating systems through which the catalyst is continuously circulated countercurrent to the oil vapors. This system is recognized as a short, low-cost way to more source materials for 100-octane gasoline, butadiene, and toluene.

Another improvement in catalytic cracking is the Fluid-

Flow process in operation by the Standard Oil Company of New Jersey. In this process, instead of passing oil vapors through a catalytic bed, the process uses a powdered catalyst so fine that it acts like a liquid—is carried along by the very vapors it cracks. The catalyst ranges from 30 mesh down to a few microns in size. As a powder, the catalyst exposes an enormous amount of surface. In the reaction chamber the oil is quickly cracked and the vapors, gases, and carbon-coated catalyst move on, the catalyst is separated out, regenerated, and thus made ready to use again. Meanwhile the cracked oil goes into conventional fractionating towers from which emerge base stock for making 100-octane gasoline, special octane blending agents, and other hydrocarbons which are the raw materials for alcohols and butadiene.

Researches in the oil industry are tending toward the production of single hydrocarbons as gasoline in order that the combustion conditions of the modern motor may be controlled to a high degree of exactness. With the mixture of hydrocarbons now in general use as gasoline, precision control is not possible. The motor fuel of the future will probably be a blend of a few hydrocarbons, with the proper volatility to suit prevailing climatic conditions, with an octane rating of around 100, and accurately adjusted to give all the other required properties. Looking upon the situation that is indicated after the war, the petroleum chemist sees all existing motors as out of date. Weights of post-war cars may be half of what they are now. The power output per cubic inch of piston displacement may double or even treble present values. The fuels, which will also yield more miles per gallon, will thus be "tailor made."

Whether in the bitter cold of the Arctic or in the uniform fifty-below-zero temperature of the stratosphere, machines of war have a job to do. Their motors and gears require

lubricants that flow, that lubricate thoroughly at all times. Chemicals of the sulphonate type are blended with the oil or grease at the refinery. Such lubricants permit oil to reach moving parts instantly, and gear lubricants are always efficient even under the most severe conditions. These materials, the real composition of which is kept secret, permit the oils to have only a small change in viscosity with enormous changes of temperature. The lack of such a product may well be one of the contributing reasons why Germany's power is much weaker in the severe winter cold of Russia.

War has created new and unforeseen shortages that must and will be met. Diplomatic and military defeats have created a drastic shortage of rubber. Few people can realize the immensity of the task that faces the rubber industry in changing over from the use of natural rubber to synthetic raw materials. Entirely new manufacturing and compounding techniques are required. For not only is there a fundamental difference in the various synthetic raw materials, but in their processing characteristics and in the properties of the finished goods as well.

Most people think of synthetic rubber in terms of tires, tubes, and similar finished products. But to the rubber goods manufacturer it is simply a new raw material out of which he must fashion such products. For the various chemical compounds we call synthetic rubber are very different from the stuff that comes from the trees. In fact, they have very little in common with natural rubber except resilience and elasticity—the ability to stretch and bounce. This, of course, does not mean that they are inferior. On the contrary, some are decidedly superior in many respects. But it does mean that the manufacturer must develop new compounding materials and new processing techniques. The manufacture of synthetic rubber can be as temperamental as the compound

itself is complex. And time is so important—for millions of tons of chemical rubber are needed to help bring the war to a victorious conclusion. Reserves of raw rubber amounted to about 700,000 tons at the beginning of 1942 and synthetic rubber capacity was scheduled at the rate of 40,000 tons per year. Contrast with this the first synthetic rubber program which called for 886,000 tons in one year.

When Bernard Baruch and his committee estimated last summer that the country must have about one million long tons of synthetic rubber a year to get by, that sounded to the public like the final word. But, not long ago, the United States learned that it was going to have to get along with a lot less. From Economic Stabilizer Jimmy Byrnes came an order to blunt Bill Jeffers: as Rubber Director, he could have top priorities on only enough key equipment to produce 425,000 tons of synthetic rubber this year. The vital materials for the original program could only come from still more desperately urgent war needs—building of naval escort vessels and manufacture of high-octane aviation gasoline.

In general, the synthetic rubber is at least equivalent to the natural. Synthetic rubber is superior in gasoline, oil, and chemical resistance; is more stable to light and air; and has greater wearing properties. Some trucks using synthetic rubber tires have gone over 35,000 miles. One may feel certain that as good as synthetic rubber is today, it will be far surpassed by that yet to come. Producers of natural rubber depend upon the life cycle of the rubber trees, and climatic and soil conditions—while the chemically-produced rubber will ultimately have the exact properties for which its structure and use were designed.

There are some six varieties of synthetic rubber which exist in the form of many types and grades. Well over a thousand different synthetic rubbers are known and no one

of them is a chemical duplicate of natural crude rubber. Of these six varieties, four of them, namely, Thiokol, Neoprene, Koroseal, and Butyl, originated in this country.

The several types of synthetic rubber being marketed under the name "Thiokol" are the result of research initiated in early 1920. It is produced by the Thiokol Corporation from the non-critical materials, ethylene, sulphur, and salt. The basic chemical reaction involved is that between sodium polysulphide and ethylene dichloride. Thiokol is proving to be a very satisfactory tire-tread material and may be the answer to required retreads.

About ten years ago du Pont was actively engaged in a search for a method of making butadiene rubber from acetylene. In the course of the research the acetylene was treated with hydrochloric acid giving a rubbery material. The resultant "Neoprene" is now produced by the polymerization of the addition-product of vinyl acetylene and hydrogen chloride. This new material found its way into literally thousands of different products where it proved of inestimable value. It was used despite the ready availability of natural rubber and despite a substantial difference in price. Since early in 1941 it has been so much in demand that it was necessary to place it under mandatory priority control. Engineers use it in the form of molded goods, as diaphragms, belting, lining in oil hose, in the construction of barrage balloons, and for heavy-duty tires.

Goodrich's Koroseal is produced by the polymerization of vinyl chloride with itself or with other compounds like vinyl acetate. Its distinction is resistance to chemical attack. But it lacks elasticity. It is used by the ton for cable covering on battleships because it will not burn.

Another type of rubber is based upon the dehydrogenation of isobutane, obtained from natural or cracked gases, to

isobutylene. This is polymerized with some butadiene or isoprene resulting in a product called Butyl rubber. Butyl rubber is not as good a synthetic rubber for tire use as the Buna-S. The last type, and the one looked to at present as the most satisfactory, is "Buna" rubber. The two best known Buna compounds are Buna-N and Buna-S. Buna-N is the result of building up butadiene and acrylonitrile; and Buna-S is butadiene with styrene. Compared to natural rubber, Buna-S is poorer in tear resistance, heat build-up, and flexing, but superior in aging and resistance to abrasive wear.

Since styrene is now readily made from coal and oil, the chief problem of supply is to make the butadiene. The chemist has a choice of processes—to make butadiene from petroleum products, from starch (grain or potato), or from acetylene. Russia elects potato starch as her basic raw material, converting it into alcohol and by a catalytic process, converting the alcohol into butadiene. Our chemists have greatly improved the Russian process, and there was powerful pressure from farm interests to make this the official method. Claims of quicker production, lower costs, and the use of less critical metals in construction, filled the air with controversy. However, the oil companies began their work earlier, and have contracts. On January 30th there was an announcement that the new Standard Oil Company plant in Louisiana had started production of butadiene with an estimated output of 9,000 tons per year. Many other plants have been producing butadiene in large quantities.

Certain special uses of synthetic rubber are new. When you read of a badly shot-up American plane returning safely to its base, the chances are that Butyl rubber deserves a share of the credit. That is because all American battle planes being built today have gasoline tanks protected by a bullet-sealing lining of soft gum insulated by a gasoline-resistant

synthetic rubber. So swift and efficient is the self-sealing action of these linings that they lose only a few drops of gasoline when pierced by bullets that leave jagged, fist-big holes in ordinary metal tanks.

Government and transportation officials recently inspected a special test car of the Pennsylvania Railroad which was fitted with synthetic rubber bags containing oil. One of these bags, when inflated, will hold about 13,000 gallons of liquid. The development of these bags may convert freight cars into rolling tankers, cargo planes into flying gas stations, thus providing some relief to the present petroleum transportation problem. Small filling stations that float on the sea like buoys have been developed by Navy men for the quick refueling of submarine-hunting seaplanes and other aircraft. The "filling stations," fuel-filled balloons, are lowered into the sea where they float.

Medium sized tanks require around 500 pounds of rubber, a pontoon for a bridge 1,000 pounds, each gas-mask uses about a pound, and a battleship uses up to 150,000 pounds.

In its growth the Plastics industry has followed two paths of endeavor: that toward the improvement and creation of new thermoplastic materials, as typified by Hyatt's celluloid; and that toward the improvement and creation of thermo-setting materials as typified by Baekeland's plastics. Hyatt, in 1868, discovered that nitrocellulose, combined with camphor, gave celluloid which was a desirable substitute for ivory. By the careful study of the illusive chemical reactions involved, Baekeland succeeded in finding methods for controlling the action of phenol and formaldehyde. He produced a beautiful, hard, transparent material that looked very much like natural amber.

Search for an ester of cellulose, more stable and less flammable than the nitrate, led to the development of the

acetate. Cellulose acetate is made so clear that it is widely used in the manufacture of shatterproof glass. Research led to a new group, the vinyl plastics. First were the esters of vinyl alcohol—vinyl acetate and vinyl chloride. The casein plastics—the base material being milk—appeared over twenty years ago.

Among the thermosetting plastics are urea formaldehyde condensation products like Beetleware; others of melamine formaldehyde like Melamac and some like Bakelite and casein. Among the thermoplastic types are Pliofilm, which is so freely used as a protective covering in sheet form and is made by adding hydrochloric acid to the unsaturated linkage in rubber; Neoprene and Koroseal which have already been discussed; the cellulose acetate as Celanese; the safety film, used in projection lanterns, called Lumarith; the methacrylate resins used in the aviation industry as Plexiglas and Lucite; Rayon and Cellophane, which are merely reprecipitated cellulose; and finally, Nylon.

In 1928 chemical research developed a material with far-reaching implications, both in the scientific and commercial worlds. This material was called Nylon—the first truly synthetic fiber. The so-called "66" polymer, made by the reaction between hexamethylenediamine and adipic acid, was developed. In 1938 du Pont announced the development of this Nylon from which could be spun textile fibers surpassing, in strength and elasticity, any previously known textile fiber either natural or synthetic. It is remarkable that Nylon can be made from such abundant raw materials as coal, air, and water, and that it can be fashioned into material as fine as a spider web or as thick as a man's arm. The first commercial plant went into operation in 1940. Today the entire production facilities of du Pont's two Nylon plants are being devoted to the manufacture of products for use in connection

with the war effort. A process, to make new Nylon out of old, has been completed—thus converting ladies' used Nylon hose into parachute cloth and similar materials.

Early in the defense program the Army and Navy evolved a beautiful pair of ground glass goggles mounted in precisely machined metal frames. Even before the approved design went into production it was clear that they could not be provided either in time or in required quantity. Here a crisis was averted by the Polaroid Corporation, which had developed a new process for finishing the surface of cellulose acetate sheets which gave the plastic the optical qualities of fine ground and polished glass. The result was the interchangeable plastic lens in a snug-fitting frame of molded synthetic rubber. For protection against wind, a clear, "Wind-foil" lens is worn. When the sun grows bright and glare becomes bothersome, the Polaroid "Glare-foil" lens is snapped into place.

A very important use of Plexiglas is for the production of hoods for pilots and gun turrets on airplanes where high visibility is so essential.

Laminated safety glass is a result of much research. Ceramic chemists worked out suitable formulae for the glass. Chemists developed the plastics which are being used in the interlayer, evolved the plasticizers that render this interlayer flexible, and invented compositions to make the plastics adhere to the glass. The plastic interlayer employed in the original "Triplex" was cellulose nitrate. This material decomposed under the influence of the shorter wave-length portion of solar radiation, turned brown, and lost its adhesion properties. Cellulose acetate, which is now used, is not appreciably affected by sunlight and does not decompose. When broken, the glass fragments remain anchored to the plastic and also yield to applied force. A new laminated glass,

made with acrylate resin, bulges under impact and thus absorbs the kinetic energy of the blow. To develop bird-proof windshields for airplanes, Westinghouse shoots previously electrocuted poultry from a 20-foot air gun at a pane of glass. One type of panel developed has tempered glass on the outside, an air space, then two panes of glass holding a half-inch filling of plastic. These panels protect from a 300-mile-per-hour poultry bullet.

One of the first industries in America was the manufacture of glass. In 1608, Captain John Smith established a glass factory at Jamestown, Virginia. During the following three centuries the glass industry was essentially a rule-of-thumb process. Today the glass industry has emerged from the ages of closely-guarded secret formulae and empirical processes, to a full use of the tools of modern science. The outstanding advantages of glass are its inertness, durability, transparency, and cleanliness. The Corning Glass Works has developed a glass with high heat resistance coupled with high chemical stability. This "Pyrex" glass has the lowest coefficient of expansion of any commercial glass, which makes it unequalled in its ability to withstand sudden temperature changes.

The first glass-lined steel tanks were manufactured solely for the bulk storage of malt beverages. Their advantages gradually led to their adoption by other industries, particularly chemical and food. The linings are of complex borosilicates which are fused to the steel at temperatures averaging about 1800° Fahrenheit. It is the glass-lined tank car and truck tank which has made the hauling of bulk milk practical. The thermal expansion of these enamels can be conveniently controlled by adjusting the sodium oxide and the boric acid contents, the former raising the expansion and the latter lowering it.

A special use of Pyrex is found in the construction of a telescope with a 200-inch, 20-ton reflecting mirror. For electrical insulation, glass filaments are spun and make a flameproof wire coating for use in heavy bombers. Glass fiber boards are used for heat insulation in fighting planes and in the new Arctic shelters for the Army Air Forces where the temperature falls to 65° below, with howling snowstorms. Glass foam has found use in displacing cork in life preservers and life boats. Spun glass is used as a fireproof textile. Some of the newer optical glasses use no sand at all, but depend upon the rare earth elements such as tantalum, tungsten, and lanthanum. The glass made from these materials is highly satisfactory for use in aerial photography lenses, giving more sharply defined images at higher altitudes.

The basic idea which is stimulating industrial activity is generally chemical information. The enormous industrial plant, consisting of an amazing variety of machines and equipment, is the scientific outcome of translating this knowledge into useful production. For instance, in the making of fertilizers, explosives, and other chemical compounds, nitrogen is extracted from air's inexhaustible supply. From raw sulphur is made sulphuric acid—the use of which may be taken as the index of a country's industrial activity. From common salt comes, by electrolysis, caustic, chlorine, and hydrogen. Phosphate rock is chemically altered to fertilizer and other valuable phosphorus compounds. When sufficient heat is applied, shell and clay become cement; clay is changed to brick and tiling; sand becomes glass; coal yields coke for our steel mills, ammonia for fertilizer and tar for innumerable uses. Cane and beets supply us with our rationed sugar. Wood is distilled for acetic acid, turpentine, and rosin, or is chemically disintegrated to furnish high-grade cellulose for paper, viscose, and nitro-cellulose. There are the mammoth

industrial enterprises which supply us with prepared foods, drugs, dyes, flavors, essential oils, photographic materials, and myriads of other necessary products.

Farm chemurgy is defined as putting chemistry to work for the farm. Great gains in national wealth have come largely from new inventions, new scientific discoveries, and the utilization of neglected materials. Grains are being converted into alcohols. Oathuils yield furfural. Soybean oil is used in paints, while tung and linseed oils are used in varnishes. Cornstalks and sugar-cane bagasse make insulating board. Cotton furnishes cellulose for nitro-cellulose. The cottonseed meal is used for stock feed and fertilizer. The cottonseed oil becomes a valuable feed in the form of salad oils and lard substitute. By the addition of hydrogen, it is possible to transform the oil into solid shortening. Fluffing with nitrogen inhibits oxidation and makes it stable for longer periods of time. Dextrin, made from sweet-potato starch, is used as an adhesive on postage stamps. Agripol and Noropol are synthetic rubbers made from the fatty acids of vegetable oils. Ethylene is used for the purpose of rapidly ripening fruits. The speed of growth of potatoes has been increased nearly 100 per cent when the seedlings have been treated with ethylene. Insecticides, fungicides, and disinfectants have been developed to protect the crops.

When the nation entered the first World War in 1917, there existed no organization in the Army devoted to the pursuit of chemical warfare or to protection against it. This handicap, however, was largely overcome thanks to the feverish researches of many American chemists. This new and revolutionary form of warfare became so important that it was necessary to establish a separate organization within the Army devoted to the study of chemical warfare.

The Allies did not believe that the Hague rules of warfare,

which prohibited the use of poison gases, would be wantonly broken. But in April, 1915, the Germans launched the first gas attack. The military situation had reached a stalemate and the vast stage was set. With all weather conditions correct, several thousand cylinders of chlorine gas, previously installed in the German trenches, were opened. The poisonous gas, drifting over the soldiers of two French divisions was so unexpected, so powerful in its effects, so sudden, that the men who were not overcome fled in terror and confusion. The attack was devastating in its effects. The German troops were able to penetrate, unopposed, to a depth of three miles where they entrenched. Had they pushed on, they might have been able to reach the sea, thus breaking the blockade which slowly but surely was starving Germany into submission.

From that day each warring nation mobilizes its chemists to devise offensive and defensive methods of chemical warfare. Thousands of compounds have been investigated to determine their suitability, but the requirements which chemical warfare agents must possess are so specific and rigid that not more than a score have been found to have value. Chlorine is an irritant. It causes inflammation of the respiratory organs, produces quick disability, and may cause death. Phosgene or carbonyl chloride is a colorless gas having a sweetish odor. It, too, is a lung irritant. It is much more toxic than chlorine. The next development was the use of chloropicrin, which causes nausea and made it impossible to keep the gas-mask in position. Mustard gas, or beta chlorethyl, dissolves in skin or lung tissue and produces serious burns. It is a highly effective casualty producer. Lewisite is another dangerous agent. The lacrimators, or tear gases, produce a copious flow of tears and intense eye pains. The Army chemists have developed a standard gas mask which

provides complete protection to the eyes and to the respiratory organs, against all known chemical warfare agents. Methods are being worked out for the protection of the body and suitable material for this purpose has been produced.

In the present war, chemical weapons have as yet played no important part; but smoke screens and incendiary agents are being used. Both Great Britain and Germany have made great efforts for defense against gas attacks, and doubtless both nations have the means to conduct vigorous offensive action with chemical agents. Possibly the fact that Germany is unable to keep her enemies from coming over her country accounts for her not starting chemical warfare. But it is by no means certain that chemical warfare will continue to play a negligible rôle in this conflict.

The nation will emerge from this war with enormous capacities for making plastics, synthetic fibers, nitrates, hydrocarbons, high-octane fuels, and many other raw materials on a scale that only two years ago was beyond our comprehension. In a world at war the impression is given that all forces are used solely for destruction. When the war is over, the new technology will quickly, efficiently, and effectively convert the war effort to peacetime pursuits with amazing speed. With the tremendous pressure of necessity, commercialization of processes has occurred which would have taken years under normal conditions to complete.

But now Chemical Industry is fighting for an American victory and an American peace.

A. J. Hartsook.

VII

PHYSICS AND THE ART OF COMMUNICATION

THE first important contribution of physics to the art of communication was the electric telegraph early in the last century. This was followed by the telephone some years later, and then, at the end of the nineteenth century and the beginning of the twentieth century, the wireless telegraph was developed by Marconi, and this was followed a few years later by the wireless telephone, or radio broadcasting. It will not be possible for me to discuss all these different modes of communication, so I am going to confine myself to radio broadcasting, and I think that is the most interesting as well as the most recent of these methods of communication.

In radio broadcasting the speaker talks into a microphone, or mike. This generates an electric current which is conveyed to the transmitting station. In the transmitting station there is an electric oscillator, in which electricity oscillates to and fro and emits electric waves. These electric waves travel out into the surrounding space and can be picked up by receivers thousands of miles away. The receivers contain an electric oscillator which is tuned to the oscillations of the transmitting oscillator. The current from the microphone is made to modify or modulate the oscillations of the transmitting oscillator, and so the electric waves emitted are modulated to correspond to the sound of the speaker's voice. When the waves are picked up by the receiving oscillator, the modulations are impressed on the oscillations of the receiving oscillator, and are then transmitted to a loudspeaker, which

reproduces the sound of the speaker's voice. So the whole thing is rather complicated, and I am going to talk about the principles involved in this process, omitting technical details.

The electric waves which carry the message travel through the air around the earth. The air, however, takes no part in this transmission. The electric waves will travel equally well through empty space. Although they do actually travel through the air, the air does not help them or hinder them in any way. They could travel equally well through a perfect vacuum.

Now there are three different kinds of effects which can be transmitted by what we call a perfect vacuum. They are electric effects, magnetic effects, and gravitational effects. We all know of course that the earth attracts bodies near it and that this action takes place through a vacuum just as well as through the air. So a gravitational attraction is one of the actions which is transmitted through a perfect vacuum.

I can very easily show magnetic effects or actions with two magnets. We stand one up, and if we bring another magnet near it, it attracts it, but if we take the other end of the magnet, it repels it. Or if we put the two magnets side by side and they repel each other, they will fly apart. If we turn one the other way, then they attract each other. There you have an action which is transmitted through so-called empty space. That is the magnetic action.

Now electric actions are also transmitted equally well through empty space. I have here a rod of lucite, which I will rub with a piece of flannel and it will then become electrified and will attract this ball, and that action will take place across empty space. It can be shown in another way. I have here an electric detector, which I am going to explain later on. Just now I am going to show the action of the electricity on this lucite rod. Here is a small neon lamp, and

the apparatus is arranged so that the electrical attraction of the electricity on the lucite rod will turn off the lamp. Notice that the lamp goes out when I pull the rod away.

There are two kinds of electricity. This electricity we have on the lucite rod is called positive electricity. Now if I take a piece of hard rubber and rub it with cat's skin—cats are supposed to be rather electrical, so cat's skin is considered good for this purpose—you will see that the lamp goes out when I move it towards the apparatus. It comes on when I pull it away. So the effect is just the opposite of the effect obtained from the lucite. The lucite gets positively electrified when we rub it and the hard rubber gets negatively electrified. So the electricity exerts an effect, you see, across empty space.

So we have electrical and magnetic and gravitational effects which are transmitted across empty space.

At one time it was thought that space was merely volume, or that space just had length and breadth and thickness, and so occupied volume, but there was nothing there. It was just empty. But now we know that space has physical properties. It has the properties of transmitting gravitational effects and electric effects and magnetic effects. These properties of space are just as much the properties of space as the geometrical properties. At one time during the nineteenth century it was argued that, since empty space would transmit these magnetic and gravitational and electric actions, there must be, besides space, a medium present which transmitted these actions. This medium was called the ether, and it was said that the electric and magnetic effects were transmitted through the ether which occupied the otherwise empty space. That idea has now been given up. We do not think now of the empty space as filled with ether. Of course if it is filled with ether it is not empty. But we do not separate the two things.

We say that there is space, and space has these geometrical and physical properties which cannot be separated, and therefore the idea of an ether filling the space has been given up. The observed properties are the properties of space.

The most interesting thing about radio broadcasting is the way the message is transmitted from the transmitter to the receivers, and this transmission is said to be due to electric waves. The electric telegraph, where you have a wire, was once described as something like this: "Suppose you had a very long dog and his tail was in New York and his head was in Boston. Then you could pull his tail in New York and he would bark in Boston," and that was like the electric telegraph. But with wireless there is no dog. There is nothing but space in between. So I want to talk about these electric waves.

There are two important properties of electricity and magnetism. It is found that a moving magnet produces an electric field, or will generate an electric current. Of course if the magnet moves, then the magnetic field moves with it. So we have a moving magnetic field. Now it is found that a moving magnetic field produces an electric field. I can show that by an experiment here. I have a coil of wire—a lot of wire wrapped in a coil—connected with a galvanometer, which will indicate an electric current. If I push a magnet into the coil it will produce a current which will be indicated by the galvanometer. If I move it in, I get a current. If I hold it still, there is no current. If I move it out, we get a current in the opposite direction. So you see the magnet produces or excites in the surrounding space a magnetic field, and when this magnetic field moves across the wires in this coil, an electric current is generated in the coil. The electric current in the wire is produced by an electric field acting along the wire. So we see that the moving magnetic field generates an electric field.

Now there is a sort of reciprocal relation. An electric current, that is, moving electricity, or a moving electric field, will produce a magnetic field. I have another experiment here to show that. Here I have a coil of wire with an iron bar through it. If we pass an electric current through this coil, it will produce a strong magnetic field. One way of showing that is to put some nails close to the bar and then pass a current through the wire. The nails are attracted to and stick on to the iron bar; if we stop the current, they drop off. Another way of showing it is to have two magnets. Suppose I put up a magnet near one end of the iron bar and another magnet near the other end. When I turn on the current they are attracted by the bar. Now I will turn them upside down and then turn on the current, and you see now they are repelled by the bar. You see the iron bar becomes strongly magnetized. It repels one end but attracts the other end of a magnet. Of course these magnets will attract the nails.

So then it appears that a moving magnetic field produces an electric field and a moving electric field, which you get with the current, because in a current the electricity is moving along, and so the electric field of the electricity of course moves along with it, and produces a magnetic field.

Now in radio broadcasting electric oscillations are used. Oscillation means movement from side to side or backwards and forwards. For example, if you take this lucite rod and rub it so that you have some electricity on the end, then one way of getting an electric oscillation would be simply to move it backwards and forwards; then you would have the electricity moving backwards and forwards, or oscillating, which will produce electric waves. So in order to produce electric waves all we have to do is to get the electricity to oscillate backwards and forwards. To produce the waves used in broadcasting the rate of oscillation has to be very high—millions of times per second.

An electric oscillation is similar to a mechanical oscillation. I have here a weight on a spring. If we pull it down, it will oscillate up and down. That is what we call a mechanical oscillation. To get an electrical oscillation, suppose we take, as I have here, a metal ball connected by a wire to another metal ball. Now suppose you have positive electricity on one ball and negative on the other. Then the positive electricity attracts the negative electricity so that they tend to move together. In fact, you get a current along the wire. The electricity flows along the wire so that the positive electricity flows towards the negative and the negative electricity flows towards the positive, and they neutralize each other; that is, equal amounts of positive and negative electricity, when put together, destroy each other. Thus you get a current and the electricity disappears. The positive flows towards the negative and the negative flows towards the positive and they neutralize each other, so that the charge disappears.

At first, then, you would think there would be no oscillation. The charges would simply disappear. But when the electricity flows along the wire you get a magnetic field, because the moving electric field produces a magnetic field. So you get a magnetic field which is around the wire. The current at first increases and then gets smaller as the charges neutralize each other. When the current begins to diminish, the magnetic field, which is produced by the current, also diminishes or moves away; but we have seen that a moving magnetic field generates an electric field, so that as the current diminishes the diminishing magnetic field keeps the current flowing. So the magnetic field around the rod, when the current begins to get smaller, helps to keep the current going. So, instead of the current just stopping, it goes on until the ball which was negative becomes positive and the other ball becomes negative; that is, you start with positive at one end

and negative at the other end, and then the positive goes to the other end and the negative also goes to the other end, and then it begins all over again; the positive goes back and the negative also, and again you get the magnetic field which keeps the current going, so instead of the positive and negative just neutralizing each other and the current stopping, you get an electric oscillation from one end to the other and back again. You get the current first going one way and then the other way. The current oscillates and we get what is called an alternating current. That is the way in which electric oscillations are produced. It is similar to the oscillation of a weight on a spring. If you pull the weight down, then the spring pulls it up, but when it gets to its equilibrium position it does not stop; it overshoots the mark and goes too far up, and then it comes down again. It is analogous to the way in which the electric oscillations occur.

When a body is moving, it tends to keep on moving. It has inertia. So when the spring has pulled the weight up and has it moving, it goes on moving; it goes too far, so to speak, and then comes back, and so keeps on oscillating up and down. Electricity does very much the same thing. When the positive charge moves across the wire it produces a magnetic field, and the magnetic field is analogous to the motion of the weight and keeps the current going, because when the magnetic field diminishes it generates an electric field and so keeps the current going, and the current, so to speak, overshoots the mark and the positive charge that was on one ball goes to the other ball, and the negative charge which was on one ball goes to the other ball, and that process is repeated. So you get the electric oscillations.

I have an experiment here on electric oscillations. We have what is called a Leyden jar. It is a glass jar and the inside and outside have metallic coatings. The outside coating is con-

nected with a wire, and the inside coating is connected with another wire. The two wires are connected to two knobs with a small gap in between. Now if we put positive electricity on the inside of the jar and negative on the outside, then when the charges are big enough the electricity will spark through the gap, and when the spark passes, the inside and the outside are connected through the spark. The spark is a conductor of electricity. Then you get a current in the wire and the positive charge on the inside flows through the wire, around to the outside. You have the positive on the inside and the negative on the outside. The positive flows towards the negative and neutralizes the negative, but it produces a magnetic field, which keeps the current going, and so the current goes on until the outside is positive and the inside negative, and you get oscillations from the inside of the jar to the outside, just as with the two balls connected by wire.

Now in order to detect these oscillations we have another similar jar, also with the outside connected to the inside by a wire, but in this case there is no gap. I have a wire here attached to the outer coating and another wire attached to the inner, and they are almost touching. The one wire is connected with the inside metallic coating and the other to the outside metallic coating, and there is a little gap between them of about a sixteenth of an inch. If we have the electric oscillations going in the first jar the current will be oscillating backwards and forwards along the wire through the spark, and the magnetic field which the moving electricity produces will act on the wire of the second Leyden jar, and will set up oscillations in it, and, if the oscillations are sufficiently powerful, it will produce sparks across the little gap. In order for that to happen, the two oscillators must oscillate with the same frequency, or, we say, we have to tune the second circuit so that the frequency of oscillation in it is the same as

the frequency of oscillation in the first circuit. That is what they call tuning in radio. You tune your receiver to the waves that you want to receive. To tune the second circuit I have a movable wire across it which can be moved about so as to alter the size of the second circuit. Now you see we are getting a little spark in the small gap. I will move the wire now to a different position. Then the circuits should not be tuned any longer. Now we do not get any spark. In order to get the oscillation in the first circuit to set up the oscillation in the second, you have to tune the second.

You get a similar effect with sound vibrations. I have two tuning forks. If we strike this one, you hear it give out a musical note and the other one gives out the same note. So the two tuning forks are tuned so they both make the same number of vibrations per second. Now if we start one of them, the sound vibrations from it, falling on the other one, will make the other one vibrate. I will stop the one that was started, and then you can hear the other one going. So you see, when the number of oscillations that one fork makes per second is the same as the number that the other one makes, then they are tuned and the one fork will set the other one going. It is just the same in the case of two electric circuits: if they make equal numbers of oscillations per second, the one will set the other one going. But if they are not tuned, that does not happen. For example, if I put a weight on one of the forks, that will alter its number of vibrations per second. Then they will not be tuned and will not set each other going.

I have another illustration of the same sort. This weight on the spring can vibrate in two ways. It can vibrate up and down, but it can also vibrate by rotating. So you see it has two ways of vibrating, and the number of vibrations per second it makes when it rotates is equal to the number it

makes when it goes up and down, so the two sorts of vibrations are tuned, and if we set one going it will set the other one going. As it goes up and down it begins to rotate, and as it rotates more, the up-and-down motion gets less. After a little while the up-and-down motion will stop and it will just be rotating. Then the rotational motion will set the up-and-down motion going. You see now it has practically stopped going up and down, but it is rotating strongly, and now the up-and-down motion will begin again. So when the two motions are tuned, one sets the other going.

When you have an electric oscillation, each oscillation emits an electric wave. Suppose we have these two balls connected by a wire one above the other, and one is positively charged and the other negatively. The positive electricity will come down and the negative go up. Then we will have the negative at the top and the positive will go up. So you will have the electricity oscillating up and down along the wire. The electric charges produce or excite in the space around them what we call an electric field. The electric field goes from the positive charge to the negative charge. We represent the electric field by lines going from the positive charge to the negative charge. Suppose the positive charge very quickly moves to the bottom and the negative charge goes to the top. Then the line that starts from the positive charge will very quickly move down to the bottom and the negative end will move to the top, and so the line will cross over itself near the balls.

If the positive charge moves to the bottom very quickly there will not be time for the part of the electric field some distance away to get reversed. It will get reversed near to the wire first, before it has time to get reversed farther out. The part of the electric field which has not become reversed then breaks off from the reversed part and moves away. The part

of the field that moves away is an electric wave. For each oscillation of the oscillator an electric wave is emitted in that way. The electric field, so to speak, breaks off from the oscillator and travels out into the surrounding space.

The electric waves travel out into the surrounding space with a very great velocity; in fact, their velocity is nearly 200,000 miles per second. So the electric waves which are produced by the electrical oscillations travel out in all directions into the surrounding space with this velocity of nearly 200,000 miles a second. It is exactly 186,000 miles per second.

Now suppose the oscillator makes a thousand oscillations per second. Then each oscillation emits a wave. So we get a thousand waves emitted per second and the waves travel 186,000 miles per second. Thus in one second the waves will be spread out over 186,000 miles. If a thousand waves are emitted per second, that is, if the oscillator makes a thousand oscillations per second, then each wave will be 186,000 divided by a thousand, that is 186 miles long. So to get the length of the waves which are produced you divide the velocity, that is the 186,000 miles per second, by the number of oscillations per second made by the oscillator.

Of the radio stations in Houston, for example, KPRC gives 950 kilocycles, that is, 950,000 oscillations per second. A kilocycle is a thousand oscillations per second. Therefore the wave length is 186,000 miles divided by 950,000, and that is just about one-fifth of a mile. So the electric waves from KPRC are a fifth of a mile long.

Now KTRH has 740 kilocycles, so the wave length for KTRH is 186,000 divided by 740,000, which is about a quarter of a mile.

KXYZ gives 1320 kilocycles, so the wave length for that station is 186,000 divided by 1,320,000, which is about a seventh of a mile.

So these waves that are used in broadcasting are ordinarily from around a quarter to a tenth of a mile long; that is, the number of waves emitted per second is usually about a million extended over the distance the first waye goes in one second, which is 186,000 miles. So you divide the 186,000 miles by the number of waves per second and you get the length of one wave.

I have here an oscillator which gives waves about two yards long, so you see it makes about 150,000 kilocycles, which is 150,000,000 oscillations per second. It is what is called a short wave oscillator. It is oscillating now. Here is another circuit which is tuned to it. When we get the oscillations in the oscillator it lights up a small lamp in the tuned circuit. When you have electricity oscillating in a circuit of course energy is used up in maintaining the oscillations. So to maintain the oscillations, power has to be supplied to the oscillator, otherwise the oscillations will stop very soon. In this oscillator we have two vacuum tubes which furnish the power to maintain the oscillations, so the oscillations go on steadily, instead of just quickly stopping after being started. Thus vacuum tubes are very important in radio broadcasting. I wish, therefore, to consider these vacuum tubes for a few minutes.

The vacuum tubes which are used so much for radio work depend on the fact that negative electricity escapes from a hot body. Suppose you have a metal wire which you make red hot or white hot. Then negative electricity escapes from it, but not positive. I have here an apparatus to show that. Here is a glass bulb which has a metal cylinder in the middle, and inside the metal cylinder is a filament, similar to the filament of an incandescent lamp. That is, it is just a hollow metal cylinder with the ends open, and inside there is a wire, which does not touch the cylinder, and there is a vacuum in

the bulb. We can heat the wire by passing a current through it. If we heat the wire sufficiently hot, then negative electricity will escape from the wire to the cylinder, so you get a current from the cylinder to the filament. Now I am going to heat the wire, and I have a galvanometer here to indicate the current. Here is a battery which is connected to the cylinder and the other end of the battery is connected to a galvanometer; the other end of the galvanometer is connected to the filament inside the cylinder. If negative electricity escapes from the filament to the cylinder, we should get a current through the galvanometer. At first there is no current because it is not sufficiently hot. As it becomes hotter we get a current. The cylinder is connected to the positive end of the battery. Positive electricity attracts negative. So if you put positive electricity on the cylinder it will attract the negative out of the filament, or, if electricity comes out of the filament, it will be attracted by the cylinder and will go across, so you will get a current across to the filament from the cylinder.

Now suppose we connect the negative end of the battery to the cylinder instead of the positive end. Then, if we have negative electricity on the cylinder, it will not attract the negative that comes out of the filament; in fact, it will repel it and drive it back into the filament. So when you make the cylinder negative, you get no current. I will reverse the battery, that is, turn it around so that the negative end will be connected to the cylinder. Of course if you did not connect the battery at all you would not get any current, but I have it properly connected. Now I will make the wire hot again. We get no current at all, though it is as hot now as it was before. Even when it is hotter than it was before we get no current. There is a great difference between positive electricity and negative. The negative escapes from a hot body, but the positive does not.

That fact is made use of in the vacuum tubes that are used so much in radio. They are made very much like the cylinder and filament we have just used. The filament is in the middle of the cylinder. But in addition to the cylinder and filament we have a wire grating which is between the filament and the cylinder. The cylinder is usually called the plate in these vacuum tubes. So we have the plate and the filament. The filament is in the middle of the plate, and between the filament and the plate there is a wire grating, which is called the grid. So there are the plate, the grid, and the filament, with the grid in between the other two.

Now suppose you have the filament hot enough so it emits negative electricity, and the plate is positive. Then you will get a negative current from the filament to the plate. The positively charged plate attracts the negative electricity that comes out of the filament, and the electricity that comes out of the filament goes through the grid, because the grid is just a wire grating with wide spaces between the wires. A little of the negative electricity may hit the grid, but nearly all of it goes through from the filament to the plate. But now suppose you put negative electricity on the grid. Then the negative electricity on the grid will tend to stop the electricity coming out of the filament, and so if you put a negative charge of electricity on the grid it will tend to stop the current. You can have such an amount of negative electricity on the grid that it nearly stops the current, but you still get a small current. If you put too much negative electricity on the grid you will stop the current entirely, because the negative electricity on the grid repels the negative electricity that comes out of the filament. Suppose, however, you have a small amount of negative electricity on the grid; then it will very much diminish the current; you will get a small current. If you change the amount of negative on the grid, diminish it slightly, the

current will increase; or if you increase it, the current will diminish; so the grid enables the current that passes through the tube to be controlled. You can control the current by putting more or less negative charge on the grid.

The apparatus used to show the difference between positive and negative electricity works with a vacuum tube. The grid is connected to a wire. Then the current passing through the vacuum tube lights up a small neon lamp. If we have a negative charge on a rod and hold it up near the wire connected to the grid, we get negative on the grid, which stops the current so it makes the lamp go out. So by the use of one of these vacuum tubes we can show the electric field of the charge on a rod of lucite or hard rubber.

These vacuum tubes are used to maintain electrical oscillations. For example, there are two of these tubes on this oscillator. Each tube has a plate, a grid, and a filament. There is a thick wire twisted around into one turn, and the two ends of this wire are connected, one end to one plate and the other end to the other plate. The two grids are connected to the opposite ends of the thick turn of wire. The connections of the two grids to the ends of the wire are, so the speak, crossed. Now suppose you have electricity oscillating through the turn of wire, going backwards and forwards along it. Then, if one end of the wire is positive, that will make the grid connected to it positive, and the grid will increase the current because it attracts the electrons from the filament, so you will get more negative electricity coming out of the filament and going to the plate connected to the other end of the wire. The plate currents therefore help the oscillation and maintain it so that it just keeps on going steadily.

Oscillators like this are used in radio broadcasting, although of course this is a very small one, that gives small

waves. The much more powerful oscillators used in broadcasting act in a similar way.

I have here an arrangement for detecting the electric waves that come out of the oscillator. It is just a long metal rod with a gap in the middle, and in the gap there is a small electric light bulb. This is not a sensitive detector, but it will detect the waves at a short distance. I am going to attach two rods to this oscillator, one to one end of the wire and the other to the other end. These wires correspond to the antennas that are used in radio broadcasting stations. Of course you know the antennas are usually vertical wires; that is, you have a vertical wire going up from the oscillator; but here I have two horizontal wires.

Now when the oscillator is working you have the electricity oscillating across from one side to the other. With this oscillator you get about 150,000,000 oscillations a second. The electric waves which are emitted will fall on the detector, and if it is tuned so that the frequency or the number of oscillations per second of the detector is the same as for the oscillator, then the waves from the oscillator will set up oscillations or currents along the detector rod and will light up the lamp. Of course if we alter the length of the rod, the light will grow dimmer and eventually go out. If we make the rod still shorter, then it will not be tuned and the lamp will not light up. Though we put them nearer, the lamp will not light up, since the rod is not tuned. You have to have the rod the right length for tuning. This rod must be approximately parallel to the other rod. If you turn it at right angles, the bulb will not light up. That is because the electric field in the waves goes across from one end of the oscillator to the other end. So when the detector is parallel to the oscillator, the field in the waves produces a current along the detector.

The magnetic field is perpendicular to the electric field. If you put a metal plate between oscillator and detector it will stop the waves. Of course with a very sensitive detector, the waves would be detected perhaps a hundred miles away, but this electric oscillator is of course not a sensitive detector.

There are different sorts of microphones that are used in broadcasting. One kind is called the crystal microphone. It is rather interesting. In a crystal microphone there are crystals, of Rochelle salt. Now Rochelle salt is rather a remarkable crystal. If you bend it slightly, it becomes electrified. So in the crystal microphones they have some plates of Rochelle salt with metal coatings and the plates are arranged so that when the sound falls on the microphone, the pressure in the sound waves slightly bends the crystals, and that causes electricity to appear on the metal coatings; then the coatings are connected to wires and you get a current through the wires that goes to the oscillator.

I have an apparatus here to illustrate this. We have two crystals of this Rochelle salt, which have metal coatings, and the metal coatings are connected to a small neon lamp. Now if we suddenly bend the crystals, the crystals will give enough current to light up the lamp, though not very brightly. By tapping the top of the container holding the crystals, which slightly bends the crystals, the lamp lights up, though the light is faint.

The microphone is connected to the grid of one of the vacuum tubes of the transmitting oscillator so that the current from the microphone changes the intensity of the oscillations. This is called modulation. The waves emitted are modulated so that the variations of intensity correspond to the sound vibrations falling on the microphone.

In the receiver the process is reversed. The vacuum tubes of the receiving oscillator are connected to the loud-speaker

so that the current to the loud-speaker corresponds to the modulations. The loud-speaker therefore reproduces the sound picked up by the microphone connected to the transmitting oscillator.

There are many technical details which have been omitted, but the principles on which broadcasting depends have been very briefly outlined.

H. A. Wilson.

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